AD NUMBER

AD481725

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution: Further dissemination only as directed by Defense Metals Information Center, Battelle Memorial Institute, Columbus, OH 43201; 3 Jan 1966 or higher DoD authority.

AUTHORITY

AFML ltr 7 May 1970

#481725

DMIC Report 223
January 3, 1966

NEW DEVELOPMENTS IN HIGH-STRENGTH STAINLESS STEELS

DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
Columbus, Ohio 43201

The Defense Metals Information Center was established at Battelle Memorial Institute at the request of the Office of the Director of Defense Research and Engineering to provide Government contractors and their suppliers technical assistance and information on titanium, beryllium, magnesium, aluminum, refractory metals, high-strength alloys for high-temperature service, corrosion- and oxidation-resistant coatings, and thermal-protection systems. Its functions, under the direction of the Office of the Director of Defense Research and Engineering, are as follows:

1. To collect, store, and disseminate technical information on the current status of research and development of the above materials.

2. To supplement established Service activities in providing technical advisory services to producers, melters, and fabricators of the above materials, and to designers and fabricators of military equipment containing these materials.

3. To assist the Government agencies and their contractors in developing technical data required for preparation of specifications for the above materials.

4. On assignment, to conduct surveys, or laboratory research investigations, mainly of a short-range nature, as required, to ascertain causes of troubles encountered by fabricators, or to fill minor gaps in established research programs.

Contract No. AF 33(615)-3408

Roger J. Runck

Roger J. Runck
Director

Notices

DMIC Report 223
January 3, 1966

NEW DEVELOPMENTS IN HIGH-STRENGTH STAINLESS STEELS

by

A. F. Hoenie and D. B. Roach

to

OFFICE OF THE DIRECTOR OF DEFENSE
RESEARCH AND ENGINEERING

DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
Columbus, Ohio 43201

TABLE OF CONTENTS

NEW DEVELOPMENTS IN HIGH-STRENGTH STAINLESS STEELS

A. F. Hoenie and D. B. Roach*

SUMMARY

Among the various types of stainless steel available, the high-strength precipitation-hardenable grades have been widely accepted by industry because of their good room- and elevated-temperature mechanical properties, corrosion and oxidation resistance, and fabricability. Recent developments in precipitation-hardenable alloys have been directed toward (1) improved transverse ductility in heavy sections, (2) greater resistance to crack propagation in sheet, (3) increased resistance to stress-corrosion cracking, (4) higher elevated-temperature mechanical properties over a wider temperature range, and (5) reduced cost. The approaches to achieving these goals include varying the chemical composition, reducing the carbon content and the amount of residual elements present, vacuum melting, and microstructure control through composition balance.

The new alloys** covered in this report include one semiaustenitic precipitation-hardenable stainless steel, PH14-8Mo, and the following martensitic precipitation-hardenable stainless steels: PH13-8Mo, 15-5PH, Custom 455, AM-363, AM-362, and AFC-77. Also included is 17-4PH as a sheet and strip product. Chemical composition, physical metallurgy, mechanical and physical properties, corrosion resistance, fabrication, and cleaning are discussed for each alloy.

*Research Metallurgist and Associate Chief, Ferrous and High-Alloy Metallurgy, Battelle Memorial Institute, Columbus, Ohio.

**Armco Steel Corporation produces PH14-8Mo, PH13-8Mo, 15-5PH, and 17-4PH; Allegheny Ludlum Steel Corporation produces AM-362 and AM-363; Carpenter Steel Company produces Custom 455; and Crucible Steel Company of America produces AFC-77.

INTRODUCTION

The Defense Metals Information Center has prepared numerous reports covering the properties of various alloys of interest to the defense industry. These documents, DMIC Reports 111, 112, 113, and 164, and DMIC Memorandum 15, describe the properties of the various high-strength stainless steels, and cover such alloys as 17-7PH, PH15-7Mo, 17-4PH, AM-350, AM-355, AM-357, and AM-359, as well as certain martensitic stainless steels and the cold-rolled austenitic stainless steels.

Since the publication of these reports, new stainless steels have been developed and marketed. Among these have been AFC-77, AM-362 and AM-363, PH14-8Mo, PH13-8Mo, Custom 455, and 15-5 PH. In addition, 17-4PH - which had previously been available only as bar, plate, casting, and forging products - has become available as sheet and strip. This report presents information on the metallurgy, mechanical and physical properties, and fabrication characteristics of these newer, high-strength stainless steels.

HISTORICAL BACKGROUND

Prior to World War II, three general types of stainless steel were available. Classified on the basis of their room-temperature crystallographic structure, these steels are the austenitic (AISI 300 Series), the martensitic (AISI 403, 410, 420, 431), and the ferritic (AISI 405, 430, 446) types. The austenitic grades contain, in addition to 17 percent or more chromium, sufficient amounts of elements such as nickel and manganese to render them austenitic from elevated to cryogenic temperatures. These steels are ductile and of low strength. They cannot be hardened by heat treatment, but have excellent corrosion resistance. They are also noted for their good strength at temperatures above 1000 F and for excellent formability.

The martensitic stainless steels contain 12 to 18 percent chromium, 0.15 to 1.25 percent carbon, together with silicon, manganese, and other elements. These steels are austenitic at elevated temperatures and transform to martensite on cooling to room temperature. As is the case with other transformation-hardening steels, these stainless steels are tempered after martensite formation. The martensitic stainless steels can be hardened to high strength, and they maintain good strength at temperatures up to about 1000 F. They are the least corrosion-resistant of the stainless steels, and they are not as fabricable as the austenitic types.

In comparison, the ferritic stainless steels are of low strength, have corrosion resistance intermediate to the austenitic and martensitic grades, and excellent oxidation resistance at high temperatures. These steels are essentially iron-chromium alloys containing 12 to 27 percent chromium, with small amounts of carbon, silicon, manganese, and other elements. They maintain a body-centered cubic structure at room temperature and at normal thermal-processing temperatures (to about 1600 F). These steels cannot be hardened by heat treatment and also lack the fabricability of the austenitic steels.

During World War II, the first precipitation-hardening stainless steel made its appearance. Known as Stainless W, this steel was developed by the U. S. Steel Corporation. The alloy, containing about 17 percent chromium, 7 percent nickel, and 1 percent combined titanium and aluminum, is martensitic when air cooled to room temperature. High strength is attained by aging at about 900 F. Stainless W's mechanical properties are quite similar to those of the standard Types 410 and 420, and the alloy is known as a martensitic precipitation-hardenable stainless steel.

During the later 1940's, Armco Steel Corporation developed a series of precipitation-hardenable stainless steels that have found wide usage. The first, 17-4PH, is similar to Stainless W in that it is martensitic at room temperature and attains full strength by precipitation of a copper-rich phase upon aging at 900 to 1150 F. This steel was originally a bar, plate, and forging stock product. The second alloy was 17-7PH steel. This steel is austenitic when annealed at temperatures of 1900 to 2000 F. In this condition, the steel is readily formable. To be hardened, the austenite must be converted to martensite in which precipitation of an aluminum-rich phase will occur on aging at 900 to 1050 F, resulting in a considerable increase in strength. The transformation of austenite to martensite can be brought about by cold work or precipitation of chromium carbides at an intermediate temperature of 1200 to 1750 F. This depletion of the matrix in chromium and carbon raises the M_s temperature so that, on cooling to room temperature or to a practicable subzero temperature, the martensite transformation occurs. This type of steel, because it is austenitic in the annealed condition, but can be made martensitic, is referred to as a semiaustenitic precipitation-hardenable stainless steel. Because it is more easily formed and fabricated than the martensitic stainless steels, it found wide usage as a high-strength structural material and was the forerunner of several steels of this type.

In the early 1950's, Allegheny Ludlum Steel Corporation developed AM-350 and AM-355, semi-austenitic stainless steels similar to 17-7PH. In the same period, Armco marketed PH15-7Mo, a modification of 17-7PH having somewhat better elevated-temperature strength. In the later 1950's, Allegheny-Ludlum developed AM-357 and AM-359, modifications of AM-355.

Thus, by 1961, the high-strength precipitation-hardenable stainless steels available consisted of

Stainless W and 17-4PH martensitic types and 17-7 PH, PH15-7 Mo, AM-350, and AM-355, AM-357, and AM-359 semi-austenitic types. These alloys developed yield strengths in the range of 160,000 to 200,000 psi or higher, depending on the specific heat treatment. These steels have been amply described in previous DMIC reports and will not be discussed here. However, over the past 5 years, modifications and new alloys of these types have been developed. Available information on their properties and processing are presented in this report.

PHYSICAL METALLURGY

Each element of a stainless steel performs two functions in defining structure, one at elevated temperature and the other on cooling from the elevated temperature. The parts played by the various elements are described pictorially in Figure 1. The effect of the elements at elevated temperature is shown in the upper portion of the figure, and the lower portion, below the broken line, depicts the part played in defining the structure on cooling to room temperature.

At the top of Figure 1, the elements are divided into two groups, the ferrite promoters and the austenite promoters. A preponderance of ferrite promoters will encourage the formation of ferrite, whereas a preponderance of austenite promoters will result in an austenitic structure at elevated temperatures. The ferrite promoters are chromium, molybdenum, vanadium, columbium, titanium, and aluminum. The elements that promote austenite are iron, carbon, nickel, manganese, copper, cobalt, and nitrogen. The structure of a stainless steel at high temperatures depends upon the relative proportion of these austenite and ferrite promoters in the alloy.

Temperature, as well as composition, is an important factor in defining structure. There are temperature limits above which ferritic steels are no longer completely ferrite. The structure will contain some austenite when these alloys are heated to the range above 1600 to 1700 F. There are also upper limits above which steels normally austenitic at elevated temperatures will begin to form some high-temperature (delta) ferrite.

The lower portion of Figure 1 illustrates the effect of composition on structure during cooling. The stainless steels that are completely ferrite at elevated temperatures undergo no phase change on cooling. The alloys that are austenitic at elevated temperatures may undergo a transformation on cooling. Stainless steels of low-alloy content usually transform to martensite as the temperature is lowered. An example of this is AISI Type 410. The more highly alloyed stainless steels, such as AISI Type 304, will retain an austenitic structure as the temperature is reduced. Steels of intermediate alloy content may or may not transform on cooling. This last group then falls between the martensitic and austenitic steels and

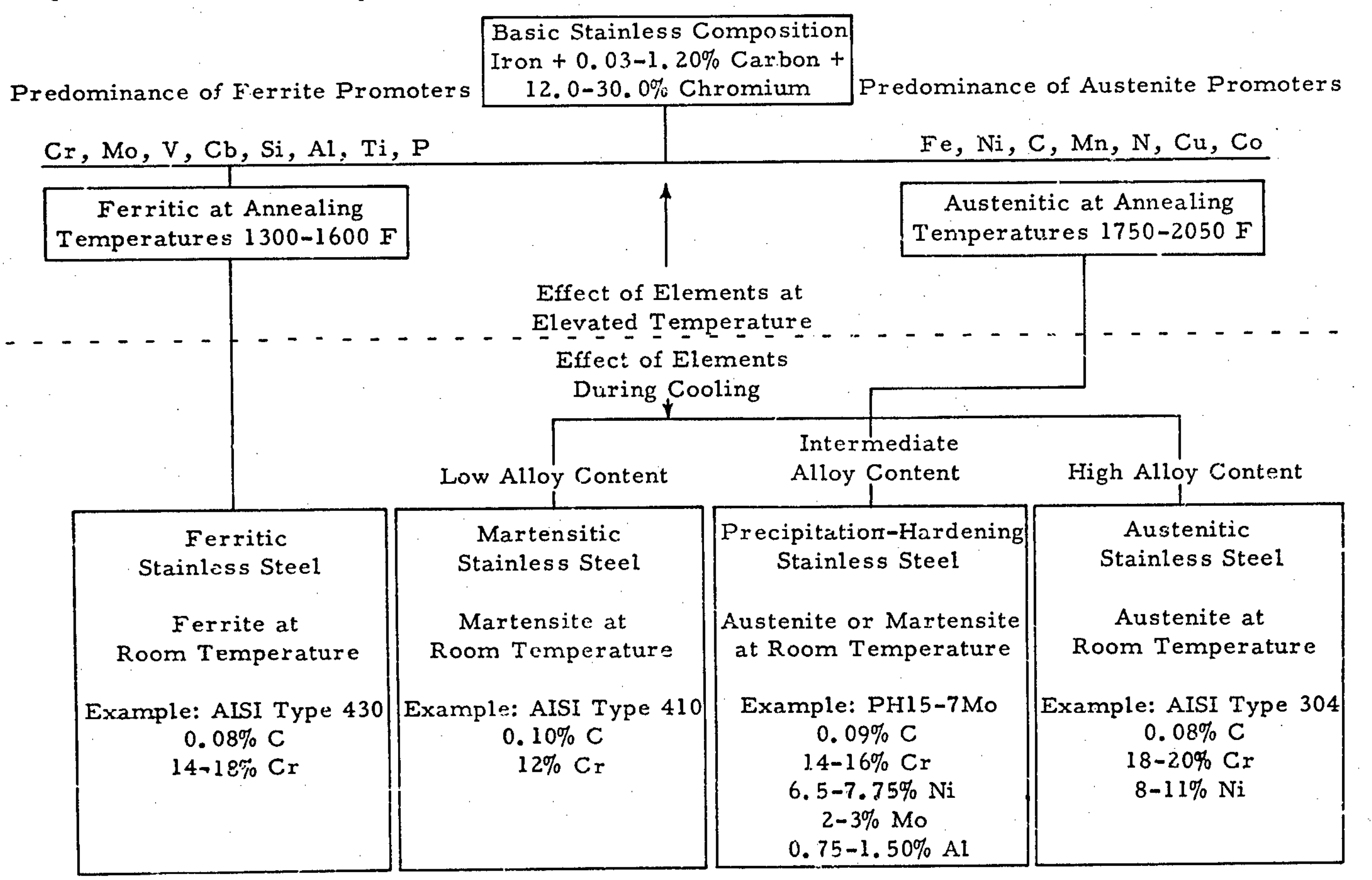


FIGURE 1. CLASSIFICATION OF STAINLESS STEEL BY COMPOSITION

includes the high-strength precipitation-hardenable stainless steels of both the martensitic and semi-austenitic types.

Figure 2 is a highly idealized phase diagram describing the combined effects of composition and temperature on stainless-steel alloys at elevated temperatures. Figure 3 illustrates the manner in which the alloy content defines the metallurgical structure obtained on cooling stainless steels that are austenitic at elevated temperatures. The symbol M_s is commonly used to indicate the temperature at which the austenite-to-martensite transformation begins on cooling, and the symbol M_f is used to designate the temperature at which the transformation is complete. In Figure 3, it can be seen that a stainless steel with low alloy content, such as Type 410, will, on cooling from elevated temperature, begin to transform to martensite at 500 to 600 F, and the reaction will be complete at about 400 F (line A-A'). As the alloy content increases, the M_s-M_f temperature range is lowered significantly. The alloys referred to as martensitic precipitation-hardenable stainless steels fall into the zone bounded by the lines B-B' and C-C'. Their alloy content is such that they are essentially martensitic on cooling to room temperature. Further addition of alloying elements depresses the transformation-temperature range until the M_f point is below room temperature (line D-D'). However, the austenite is metastable and transformation can be accomplished by refrigeration at subzero temperatures. Heating a steel of this composition in the temperature range of 1400 F causes chromium carbides to precipitate in the austenite matrix. This rejection of chromium and carbon from solution in the austenite effectively lowers the alloy content of the austenite so that on cooling it will transform to martensite above room temperature along the path described by the line C-C'. The amount the M_s temperature is raised is directly dependent on the amount of chromium and carbon

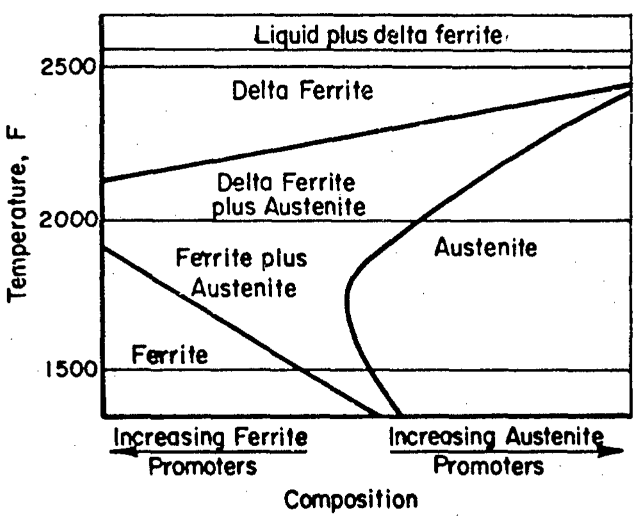


FIGURE 2. ELEVATED-TEMPERATURE CONSTITUTION OF STAINLESS STEEL

removed from solution. If, for example, a temperature of 1650 F were employed, less chromium and carbon would precipitate and the M_s temperature would not be increased significantly. In this case, it would be necessary to cool the steel to subzero temperature to induce transformation to martensite. The alloys capable of such controlled transformation fall within the composition boundary lines C-C' and E-E', and are known as the semi-austenitic precipitation-hardenable stainless steels. Further additions in alloy content depress the M_s-M_f temperature range to such an extent that the steel cannot be transformed to martensite by heat treatment. This alloy is depicted by the line F-F' and is representative of a standard austenitic stainless steel such as AISI Type 304.

With the exception of cobalt and aluminum, the elements added to a stainless steel tend to lower the M_s-M_f transformation-temperature range of those steels that are austenitic at elevated temperatures. The newly developed high-strength stainless steels have compositions falling within the boundaries of lines B-B' and E-E' of Figure 3. These steels can be transformed to martensite by cooling to room temperature or by refrigeration at subzero temperatures. The final hardening is accomplished by an aging treatment that causes coherent precipitation of intermetallic compounds in the martensite as well as tempering of the martensite. In most instances the exact nature of the precipitate has not been established. Significant precipitation does occur in some cases, resulting in greatly improved mechanical properties, while in other cases precipitation is less and the strengthening effect is marginal. The amount of precipitation and the resultant strengthening are dependent upon the composition of the austenite at the heat-treating temperature.

An important feature of some of the new precipitation-hardenable stainless steels is their very low-carbon content. These alloys, with carbon contents of 0.03 percent or less, have improved resistance to corrosion and crack propagation, and transform to a more formable martensite. Some are called maraging stainless steels because of their formability and similarity in processing to the 18-percent-nickel maraging steels. These alloys, however, because of their composition and strengthening mechanism, should be classed with the martensitic precipitation-hardenable stainless steels, 17-4PH and Stainless W, which were developed a full decade before the high-nickel maraging steels.

The specific alloys covered in this report are of the semiaustenitic precipitation-hardenable and the martensitic precipitation-hardenable types. The first group includes only PH14-8Mo. The second group includes PH13-8Mo, 15-5PH, Custom 455, AM-362, AM-363, AFC-77, as well as sheet and strip of 17-4PH.

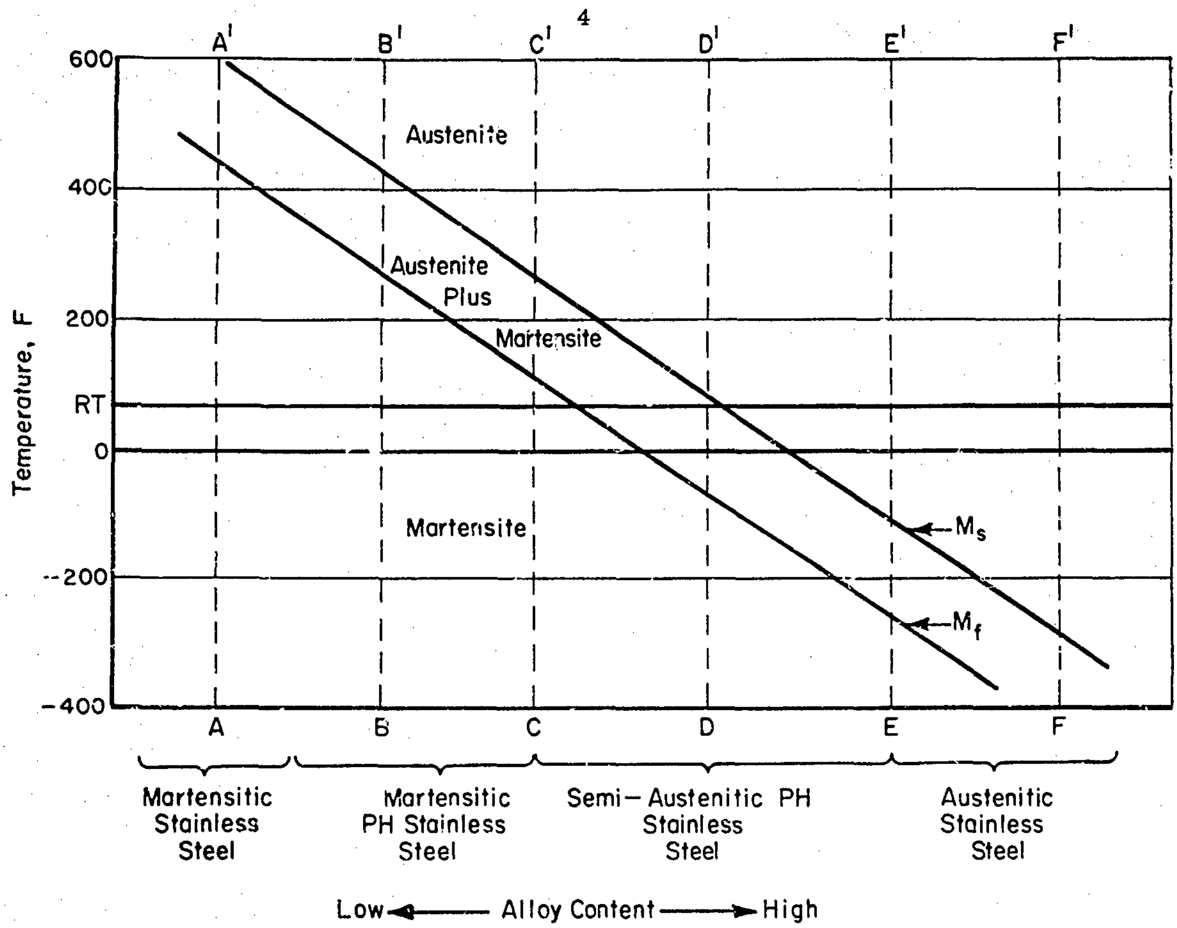


FIGURE 3. THE EFFECT OF ALLOY CONTENT ON TRANSFORMATION TEMPERATURE

NEW SEMIAUSTENITIC PRECIPITATION-HARDENABLE STAINLESS STEEL

PH14-8Mo

PH14-8Mo[1,2]* is a recent addition to the Armco family of precipitation-hardenable stainless steels. This semiaustenitic alloy was developed to provide a sheet and strip product with higher resistance to crack propagation than 17-7PH and PH 15-7Mo. PH14-8Mo is heat treatable to high strengths and exhibits good elevated-temperature properties. It is austenitic in the annealed condition, making it readily formable. The thermal processes to effect the transformation to martensite are compatible with braze-cycle heat treatments** developed for currently used stainless steels. The composition limits for PH14-8Mo stainless steel are as follows:

Element	Percent
C	0.02-0.05
Mn	1.00 max
P	0.015 max
S	0.010 max
Si	1.00 max
Cr	13.50-15.50
Ni	7.50-9.50
Mo	2.00-3.00
Al	0.75-1.50

The chromium and nickel contents have been adjusted to maintain the chemical balance required for semiaustenitic steel. In addition, the carbon range and maximum limits for phosphorus and sulfur have been lowered.

Physical Metallurgy

In the annealed condition, the microstructure of PH14-8Mo is austenitic, and contains about 8 percent delta ferrite. When PH14-8Mo is cooled from an intermediate-temperature (1700 F) conditioning treatment and refrigerated, the alloy transforms to about 80 percent martensite, 8 percent delta ferrite, and 12 percent retained austenite. Subsequent aging precipitates an intermetallic aluminum compound for additional strengthening. A total dimensional growth of approximately 0.004 in./in. occurs during heat treatment as a result of the austenite-to-martensite transformation.

*References are listed on page 39.

**Brazing operations are sometimes combined with the austenite conditioning treatment to eliminate a processing step. The temperature employed depends upon the flow characteristics of the braze alloy. The braze alloy normally will have a liquidus temperature at or just below the temperature used for RH-condition heat treatments. Brazing fixtures and/or furnace conditions usually result in slow cooling rates. To assure maximum transformation, brazed assemblies are usually refrigerated at -100 F. Aging temperatures from 950 to 1075 F are used, depending on the properties required in the brazed structure. Such processing has been termed braze-cycle heat treatment (BCHT).

Heat Treatment

The austenitic structure is attained in PH14-8Mo by heating at 1825 F±25 F and cooling to room temperature. Transformation to martensite can be accomplished by cold rolling 50 to 60 percent, or by heating at 1700 F±15 F for 1 hour, cooling to room temperature, and refrigerating at -100 F±10 F for 8 hours. To obtain additional strengthening, the cold-rolled material is aged at 900 F±10 F for 1 hour. This hardened condition has been designated CH 900 by the producer. The high-strength conditions that are reached by heat treatment alone are designated as SRH 950 and SRH 1050. They are obtained by aging for 1 hour at either 950 F±10 F or 1050 F±10 F after the refrigeration treatment. The heat-treat schedules are diagrammed in Figure 4.

Air is a satisfactory furnace atmosphere for annealing or heat treating. Electric furnaces or full-muffle fuel-fired furnaces to protect the material from combustion products and flame impingement are best suited for heat treatment. Dry hydrogen, argon, helium, or vacuum atmospheres may be used if quench rates approaching air cooling can be attained. Controlled atmospheres such as dissociated ammonia are not recommended because of the hazard of nitriding. Molten salt should not be used because of the danger of carburization or intergranular attack.

Mechanical Properties

Typical room-temperature tensile properties for PH14-8Mo in the annealed, SRH-950 and SRH-1050 conditions are shown in Table 1. The effects of short-time elevated-temperature exposure on the tensile properties of the steel in the SRH-950 condition at temperatures from -100 to 1000 F are shown in Table 2. The properties acceptable to the producer for PH14-8Mo sheet- and strip-material specifications are listed in Table 3. The effect of cold work on the tensile properties of material in Condition C and in Condition CH-900 is shown in Table 4, while Table 5 shows the effect of cold work on the tensile properties of the steel in Condition CH-950.

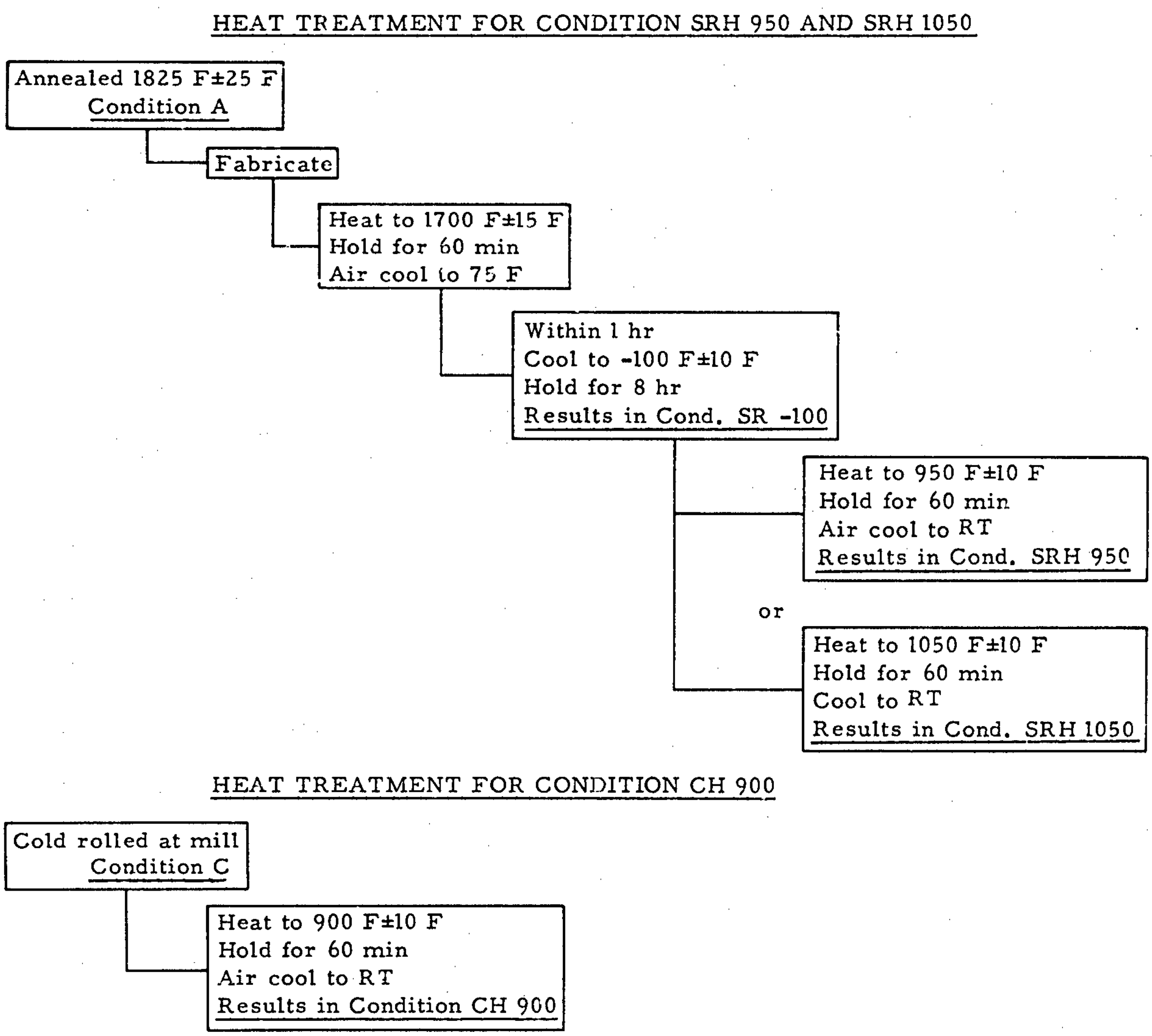


FIGURE 4. HEAT TREATMENTS FOR PH14-8Mo STAINLESS STEEL

TABLE 1. TYPICAL ROOM-TEMPERATURE TENSILE PROPERTIES OF TRANSVERSE PH14-8Mo TEST SPECIMENS

Condition	Tensile Strength, ksi	0.2% Yield Strength, ksi	Elongation, % in 2 In.	Hardness
A	125	55	25	R_B 88
SRH-950	235	215	5	R_C 49
SRH-1050	215	210	5	R_C 45

Note: Young's modulus of elasticity:
Longitudinal 28.0×10^6 psi
Transverse 29.4×10^6 psi

TABLE 2. SHORT-TIME ELEVATED-TEMPERATURE TENSILE PROPERTIES OF PH14-8Mo IN THE SRH-950 CONDITION

Test Temperature, F	Tensile Strength, ksi	0.2% Yield Strength, ksi	Elongation, % in 2 In.
	Longitudinal		
-100	267	250	11.5
80	234	218	5
500	208	182	4
550	205	180	4
600	199	176	4
650	199	175	5
800	180	153	8
1000	132	106	18
	Transverse		
-100	268	258	7.5
80	242	228	4.5
500	212	191	3
550	211	193	3
600	207	186	3
650	204	182	3
800	187	159	6
1000	135	110	17

TABLE 3. TENSILE PROPERTIES OF PH14-8Mo SHEET AND STRIP(a) ACCEPTABLE FOR MATERIAL SPECIFICATIONS

	Condition A	Condition SRH-950	Condition SRH-1050
Ultimate Tensile Strength, psi	150,000 max	220,000 min	200,000 min
0.2% Yield Strength, psi	65,000 max	190,000 min	180,000 min
Elongation, % in 2 in.			
0.020 - 0.187 in.	20 min	4 min	5 min
0.010 - 0.0199 in.	20 min	3 min	4 min
0.005 - 0.009 in.	20 min	2 min	3 min
0.0015 - 0.0049 in.	20 min	1 min	2 min
Hardness-Rockwell(b)	R_b 100 max or equivalent	R_c 46 min or equivalent	R_c 38 min or equivalent

(a) Unless otherwise stated, all values throughout this report are for air-electric-arc furnace heats of PH14-8Mo.
(b) Hardness values are not reported for material 0.010 in. and thinner.

TABLE 4. EFFECT OF COLD REDUCTION ON THE TENSILE PROPERTIES OF PH14-8Mo IN CONDITION C AND CONDITION CH-900(a)

Cold Reduction, %	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, % in 2 in.	R_C
		As Cold Rolled		
6.3	61	131	23.0	90B
11.3	65	141	16.5	21.5
22.2	78	163	11.0	33.0
29.2	109	168	10.0	38.0
39.2	150	178	8.0	41.0
49.9	177	193	2.0	43.0
59.7	207	209	1.0	43.5
72.5	222	225	1.0	45.0
		Cold Rolled + 900 F, 1 Hr		
6.3	71	129	28.5	88.5B
11.3	94	130	23.5	24.5
22.2	135	158	15.5	39.5
29.2	206	208	5.0	47.5
39.2	250	252	2.0	50.5
49.9	276	277	1.0	53.0
59.7	290	290	1.0	54.0
72.5	305	310	OG	55.5

(a) Data from 1 heat.

TABLE 5. EFFECT OF COLD REDUCTION ON THE TENSILE PROPERTIES OF PH14-8Mo IN CONDITION CH-950(a)

Cold Reduction, %	Direction	0.2% Yield Strength, ksi	Ultimate Tensile Strength ksi	Elongation, % in 2 in.	R_c	Notch Strength, ksi	Notch Strength / Yield Strength	Notch Strength / Ultimate Tensile Strength
Air Melted								
40	L	254	259	2.0	51	253	1.00	0.98
	T	260	270	1.5	51	206	0.79	0.76
60	L	273	278	2.0	52	237	0.87	0.85
	T	289	298	1.5	52	154	0.53	0.52
Vacuum-Induction Melted								
40	L	235	240	1.5	50	241	1.02	1.00
	T	256	261	1.5	50	241	0.94	0.92
60	L	258	264	1.5	50	249	0.96	0.94
	T	269	279	1.5	50	237	0.88	0.84

(a) NASA 1-in-wide edge-notch specimen.
0.0007-in. max root radius on 0.025-in.-thick sheet.
Tested at room temperature after aging 1 hr at 950 F.
Average of duplicate tensile and triplicate notch tests.
Data from 1 heat.

The resistance of PH14-8Mo to crack propagation is attributed to reduced chromium carbide precipitation at grain boundaries and at austenite-delta ferrite interfaces. This, of course, is the result of the low carbon content. Lower levels of phosphorus and sulfur also contribute to improved fracture toughness. The toughness properties of PH14-8Mo have been investigated by three different test methods: NASA edge-notch tensile, center-notch fatigue-cracked tensile, and Allison instrumented bend tests. These methods are described in ASTM Bulletin, "Fracture Testing of High-Strength Sheet Materials", (January, 1960). The results of the tests on PH14-8Mo in the SRH-950, SRH-1050, and braze-cycle heat-treat conditions are displayed in Tables 6, 7, and 8. The various thermal-exposure temperatures and times, load conditions, and mechanical properties are described in the tables.

The tensile properties of PH14-8Mo edge-notch specimens in the SRH-1050 condition at cryogenic temperatures are shown in Table 9.

Physical Properties

Limited physical-property data have been obtained. Density and thermal-expansion values are shown in Tables 10 and 11, respectively. Other physical properties, such as specific heat and thermal conductivity, can be expected to be comparable to those of other alloys of similar composition, such as PH15-7Mo.

Fabrication and Cleaning

PH14-8Mo in the annealed condition may be formed by methods presently used for austenitic or other semiaustenitic stainless steels. Typical bend diameters are one times the thickness for 90- and 135-degree bends, and two times the thickness for 180-degree bends. In springback, the alloy is similar to AISI Type 301. PH14-8Mo work hardens rapidly and may require intermediate anneals at 1825 F for deep-drawn or other severely formed parts. PH14-8Mo as hard rolled, Condition C, has limited formability. Fabrication techniques, such as those used for the cold-rolled austenitic stainless steels, should be followed.

The surfaces of PH14-8Mo parts should be cleaned before heat treatment to avoid contamination or carburization. Vapor degreasing or solvent cleaning should be used to remove all cutting oils or forming lubricants. A warm-water rinse should follow this cleaning operation.

The use of scale-preventive coatings containing organic binders offers little advantage in reducing surface oxidation at the high temperatures required for annealing or hardening. In addition, surface carburization may occur if free-air circulation around the parts is not maintained. The scale that forms at high heat-treating temperatures may be removed by wet-grit blasting or by the use of caustic scale conditioners followed by a 10%HNO_3-2%HF acid pickle. Time in the acid

TABLE 6. ALLISON-BEND TOUGHNESS MEASUREMENTS

Made on PH14-8Mo[(a)]

Exposure Temp, F	Exposure Time, hr	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Allison Parameter
		Condition SRH-950		
None		245	226	0.46
400	931	243	230	0.45
400	2592	244	232	0.45
550	100	246	233	0.35
550	1762	250	238	0.38
550	3424	250	233	0.31
550	5084	250	232	0.41
700	931	266	246	0.20
700	2592	281	262	0.11
		Condition SRH-1050		
None		218	207	0.61
400	931	217	211	0.71
400	2592	217	211	0.72
550	100	217	212	0.56
550	1762	223	216	0.62
550	3424	223	211	0.51
550	5084	222	212	0.55
700	931	242	234	0.43
700	2592	254	243	0.27
		Condition BCHT-1050[(b)]		
None		222	213	0.41
400	931	223	217	0.36
400	2592	224	219	0.36
550	100	224	220	0.29
550	1762	231	224	0.31
550	3424	230	220	0.31
550	5084	229	221	0.33
700	931	250	241	0.19
700	2592	262	253	0.11

(a) Transverse specimens were exposed to temperature under no load, and tested at room temperature.
(b) Braze-cycle heat treatment.

pickle must be carefully controlled to prevent excessive metal removal and to minimize the possibility of intergranular attack. The heat tint produced by precipitation-hardening treatments at 950 or 1050 F may also be removed by a short-time exposure to the 10%HNO_3-2%HF pickle. All PH14-8Mo parts should be passivated in a 40 to 60 percent HNO_3 solution as the final step in the cleaning procedure.

Welding

PH-14-8Mo may be welded by inert-gas shielded-arc or resistance methods. Filler metal, if added, should be of the same chemical composition. Preheating is not required, but post-heat treatment is mandatory if high-strength properties are desired. Table 12 shows the tensile properties at -100 F, room temperature, and 650 F for material welded in the annealed condition and subsequently heat treated to the SRH-950 condition. Investigation has indicated that annealing after welding and prior to heat treatment improves weld toughness. A comparison of the effects of post-weld annealing on tensile and Allison bend properties is shown in Table 13. Fracture toughness of weld metal and heat-affected zones of PH14-8Mo in SRH-1050 condition was also determined using center-notch fatigue-cracked specimens. These results are listed in Table 14.

TABLE 7. CENTER-NOTCH FATIGUE-CRACKED TOUGHNESS TESTS

Made on PH14-8Mo[(a)]

Test Conditions[(c)(d)] and Direction	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Kc,[(e)] ksi√in.	Notch[(e)] Strength, ksi
	Condition SRH-950			
No Exposure				
Longitudinal	232	215	-	202
Transverse	238	216	>172	163
1000 hr at 500 F				
Longitudinal	239	223	>177	205
Transverse	241	221	>139	169
1000 hr at 650 F				
Longitudinal	260	240	>194	197
Transverse	255	232	152	147
	Condition SRH-1050			
No Exposure				
Longitudinal	219	207	>170	202
Transverse	215	204	>165	175
1000 hr at 500 F				
Longitudinal	220	210	>172	206
Transverse	223	211	>168	182
1000 hr at 650 F				
Longitudinal	229	221	>182	209
Transverse	240	220	>174	175
	Condition BCHT 1050[(b)]			
No Exposure				
Longitudinal	217	206	-	189
Transverse	214	206	>166	167
1000 hr at 500 F				
Longitudinal	218	211	>167	199
Transverse	216	207	>167	171
1000 hr at 650 F				
Longitudinal	239	230	>186	200
Transverse	234	225	>170	155

(a) Specimens were exposed to temperature under no load, and tested at room temperature.
(b) Braze cycle heat treatment.
(c) Tensile data, average of duplicate tests.
(d) K_c and notch data, average of triplicate tests.
(e) Notch specimen size--0.050 in. thick by 2.0 in. wide, center-notched fatigue-cracked.

Corrosion

Although its chromium content is slightly lower than that of earlier semiaustenitic alloys, the general corrosion resistance of PH14-8Mo in the hardened condition is comparable to that of 17-7PH and PH15-7Mo, because of its lower carbon content and its consequently reduced amount of grain-boundary chromium carbide precipitate. The good stress-corrosion resistance of PH14-8Mo can be attributed to the same factors. Transverse bent-beam 0.050-in.-thick specimens in the SRH-950,

TABLE 8. EDGE-NOTCH TOUGHNESS TESTS

Made on PH14-8Mo in the SRH-950 Condition[a]

Test Direction	Tested at -F	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Notch Strength, ksi	Notch Strength / Ultimate Tensile Strength	Notch Strength / Yield Strength
			No Exposure			
Longitudinal	-110	267.5	239.6	246.3	0.92	1.03
Transverse	-110	256.6	242.6	202.3	0.79	0.83
Longitudinal	RT	235.1	209.8	217.1	0.92	1.03
Transverse	RT	237.3	211.9	194.7	0.83	0.92
Longitudinal	650	201.5	166.1	146.9	0.73	0.88
Transverse	650	203.2	168.1	128.5	0.63	0.76
			After 1000 hr at 650 F Under 40 ksi Load			
Longitudinal	-110	285.8	258.3	227.4	0.80	0.88
Transverse	-110	288.1	257.4	185.8	0.64	0.72
Longitudinal	RT	254.2	233.3	212.4	0.84	0.91
Transverse	RT	259.1	237.2	179.8	0.69	0.76
Longitudinal	650	212.5	190.6	130.9	0.62	0.69
Transverse	650	217.0	180.9	118.5	0.55	0.66

(a) Data developed by Lewis Laboratories (NASA). Single tensile and duplicate notch tests on 0.025 in.-thick sheet. 1 in.-wide specimens 0.0007-in.-max root radius.

TABLE 9. TENSILE PROPERTIES OF PH14-8Mo IN THE SRH-1050 CONDITION OBTAINED AT CRYOGENIC TEMPERATURES WITH EDGE-NOTCHED SPECIMENS[a][b]

Temperature F	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, % in 1 in.	Elongation, % in 2 in.	Notch Strength	Notch Strength / Yield Strength	Notch Strength / Tensile Strength
75	191.2	201.7	50	11.0	201.4	1.05	0.999
-108	195.3	230.7	50	13.2	207.6	1.06	0.900
-200	200.1	241.0	50	11.3	217.0	1.08	0.900
-321	228.8	280.7	57	15.8	180.6	0.789	0.643

(a) Data reference: North American Aviation-Los Angeles Division. Data from 1 heat.
(b) Edge-notch root radius: 0.001 in.

TABLE 10. DENSITY OF PH14-8Mo

	Condition A	Condition SRH-950
Grams per cu cm	7.82	7.71
Pounds per cu in.	0.283	0.278

TABLE 11. MEAN COEFFICIENT OF THERMAL EXPANSION OF PH14-8Mo IN CONDITION SRH-950

Temperature Range, F	Mean Coefficient, in./in./F x 10^{-6}
70-200	5.3
70-400	5.9
70-600	6.2
70-800	6.3
70-1000	6.4

TABLE 12. TENSILE PROPERTIES OF SPECIMENS REMOVED FROM PH14-8Mo WELDMENTS[a]

Tested at F	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Elongation, % in 2 in.	Elongation, % in 1/2 in.	Lateral Contraction, %	Failure	Type Fracture
-100	246	--	0.5	5	1.2	W.M.	Cleavage
75	224	189	2.25	12	5.9	W.M.	Fine
650	198	176	2.75	11	6.1	W.M.	Fine

(a) Condition: Welded + SRH 950 heat treatment.

TABLE 13. EFFECT OF POST-WELD ANNEALING ON MECHANICAL PROPERTIES OF PH14-8Mo WELDS[a]

Annealed After Welding	Condition	Yield Strength, ksi	Tensile Strength, ksi	Elongation, % in 2 in.	Elongation, % in 1/2 in.	Lateral Contraction, %	Location of Fracture[b]	Allison Parameter
Yes	SRH-950	219.0	234.7	3	13	6.5	HAZ/W	0.56
Yes	SRH-1050	210.3	221.3	3	13	6.5	W	0.76
No	SRH-950	222.2	235.4	2	8.5	4.1	HAZ/W	0.09
No	SRH-1050	211.6	218.9	3	11.5	5.9	W	0.51

(a) Specimens 0.050 in. thick; annealed where indicated at 1850 F; 1700 F for 1 hr; -100 F for 8 hr; ground flush to 0.040 in. thickness; hardened for 1 hr at 950 or 1050 F. Filler material same composition as base metal. All values are average of two to four tests.

(b) HAZ: heat-affected zone; W: weld metal.

TABLE 14. FRACTURE TOUGHNESS OF PH14-8Mo WELD METAL AND HEAT-AFFECTED ZONE (HAZ)[a]

Test Location	Test Temperature, F	Toughness (K_c), ksi $\sqrt{in.}$[b]	Notch Strength, ksi	Fracture
Weld metal	650	--	141.9	Fine
	75	>163.9	170.3	Fine to coarse
	-100	--	96.3	Coarse
HAZ	650	--	145.8	Fine
	75	>174.2	193.3	Fine
	-100	--	217.0	Fine to coarse

(a) Specimens 0.050 in. thick; conditioned 1 hr at 1700 F; -100 F for 8 hr; ground flush to 0.040 in. thickness; machined to 2 in. width, center notched and fatigue cracked; hardened at 1050 F for 1 hr.

(b) K_c determined by compliance-gage technique.

SRH-1050, and braze-cycle heat-treat conditions have been exposed on the 80-foot lot at Kure Beach, North Carolina. The results for exposure of these specimens loaded to 50 and 80 percent of yield strength are shown in Table 15.

Availability and Usage

PH14-8Mo is available in the form of sheets and strip. It is produced by electric-arc melting and by vacuum-induction melting. It is supplied in either the solution-treated Condition A or the cold-rolled Condition C. The combination of corrosion resistance, high mechanical properties, good toughness, and fabricability makes PH14-8Mo suitable for use in pressure tanks, high-performance aircraft, structural applications, as well as missile- and aerospace-vehicle applications.

NEW MARTENSITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

PH13-8Mo

PH13-8Mo(3,4) is a martensitic precipitation-hardenable stainless steel developed by the Armco Steel Corporation. The alloy can be heat treated to high strength and exhibits good ductility in the transverse direction of parts having large cross sections.

Toughness in the transverse direction is obtained by composition balance designed to prevent formation of delta ferrite in the structure, lower carbon content to minimize grain-boundary carbide precipitation, and double vacuum melting to reduce alloy segregation. The chemical composition of the double vacuum-melted heat of PH13-8Mo, from which the data reported here were generated, is as follows:

Element	Percent
C	0.042
Mn	Nil
P	0.002
S	0.003
Si	0.02
Cr	12.52
Ni	8.63
Mo	2.10
Al	1.00.

Physical Metallurgy

The chemical balance of PH13-8Mo is adjusted so that at the austenitizing temperature no delta ferrite will form. Transformation to martensite occurs on air cooling to room temperature. The alloy is further strengthened by reheating to the aging temperature, causing an aluminum-containing intermetallic compound to precipitate in the martensite.

Heat Treatment

PH13-8Mo may be heat treated by solution treating at 1825 F, air cooling to room temperature, and aging at temperatures from 950 to 1100 F, depending on the properties desired. After solution treating, the material is considered to be in Condition A. The fully hardened conditions are

TABLE 15. RESULTS OF STRESS-CORROSION TESTS ON PH14-8Mo[a]

Condition	Test Direction[d]	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Exposed at 80% of Yield Strength: Exposure Stress, ksi	Exposed at 80% of Yield Strength: Days to Failure	Exposed at 50% of Yield Strength: Exposure Stress, ksi	Exposed at 50% of Yield Strength: Days to Failure
			PH14-8Mo				
SRH-950	Transverse	241	225	180	NF[b]	112	NF
SRH-950 + 1000 hr at 650 F	Transverse	261	236	189	86 (4 of 5)[c]	118	NF
SRH-1050	Transverse	221	213	170	NF	106	NF
SRH-1050 + 1000 hr at 650 F	Transverse	242	230	184	84 (2 of 5)	115	NF
BCHT-1050	Transverse	220	211	169	NF	105	NF
BCHT-1050 + 1000 hr at 650 F	Transverse	240	226	181	105 (1 of 5)	113	NF

(a) 80-ft lot at Kure Beach, North Carolina; 0.050-in.-thick, bent-beam specimens; 5 specimens exposed per variable.
(b) NF: none failed in 268 days.
(c) 86 - (4 of 5): 4 specimens failed in average of 86 days, 1 specimen still in test.
(d) Data are not given for PH14-8Mo in the longitudinal direction, because there were no failures.

designated by the letter H followed by the aging temperature - for example, H950. PH13-8Mo also may be heat treated to satisfactory strengths by braze-cycle heat treatments currently employed for semiaustenitic precipitation-hardening stainless steels. Heat-treat schedules are outlined in Figure 5. A variation of the braze-cycle heat treatment, where the alloy is air cooled from 1700 F, refrigerated at -100 F, and aged at 950 F, has been designated Condition SRH-950.

PH13-8Mo can be satisfactorily heat treated in air-atmosphere furnaces. Inert atmospheres, such as argon, are normally used for braze-cycle heat treatments. Controlled reducing atmospheres, such as cracked ammonia, may cause nitriding of part surfaces, and are not recommended. In standard practice, parts are fabricated from material in the 1825 F-annealed condition, and only the low-temperature aging treatment in air atmosphere is required thereafter.

Mechanical Properties

Typical room-temperature mechanical properties for a double vacuum-melted heat of PH13-8Mo are shown in Table 16. These properties were developed by the two-step heat treatment shown at the top of Figure 5. The mechanical properties resulting from braze-cycle and SRH-950 heat treatment are listed in Table 17.

Precracked Charpy V-notch impact tests were conducted on double vacuum-melted PH13-8Mo in the H-900 and H-1050 conditions. This test was developed to determine toughness in the presence of an extremely sharp notch by measuring the energy necessary to propagate a crack (high acuity), and is expressed in terms of energy per unit crack area (W/A). This expression (in. /lb/ in.^{2}) is comparable to the fracture-toughness term, G_c. The results of these tests are shown in Table 18.

Fabrication and Cleaning

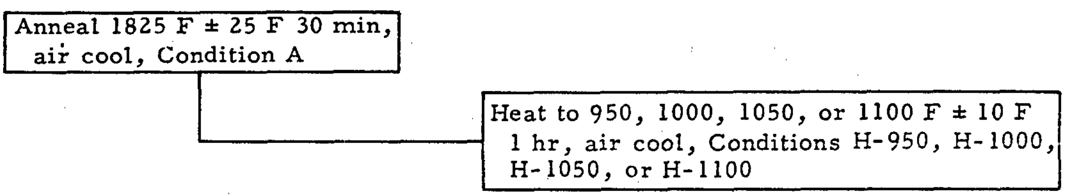
Bar or forgings of PH13-8Mo may be machined to finish dimensions from material in the annealed condition. A contraction of approximately 0.0005 in./in. occurs during precipitation hardening. Parts should be degreased and water rinsed to remove cutting oils and coolants before the aging heat treatment. The discoloration developed in the final heat treatment may be removed in the standard 10%HNO_3-2% HF stainless-steel pickle solution. Pickling time should be limited to 3 minutes maximum to avoid etching or excessive metal removal. All parts should be passivated in 40 to 60 percent HNO_3 after final cleaning.

Corrosion

Limited stress-corrosion tests have been conducted on air-melted PH13-8Mo at the Kure Beach, North Carolina, 80-feet lot. Bent-beam 0.050-in.-thick specimens heat treated to the BCHT-900 condition and stressed to 90 percent of yield strength were tested. The results are listed in Table 19.

Availability and Usage

PH13-8Mo is not yet available as a commercial product. It is being developed for large cross-section bar, billet, and forgings that require high strength and good toughness in the transverse directions.



PH13-8Mo Braze Cycle Heat Treatment

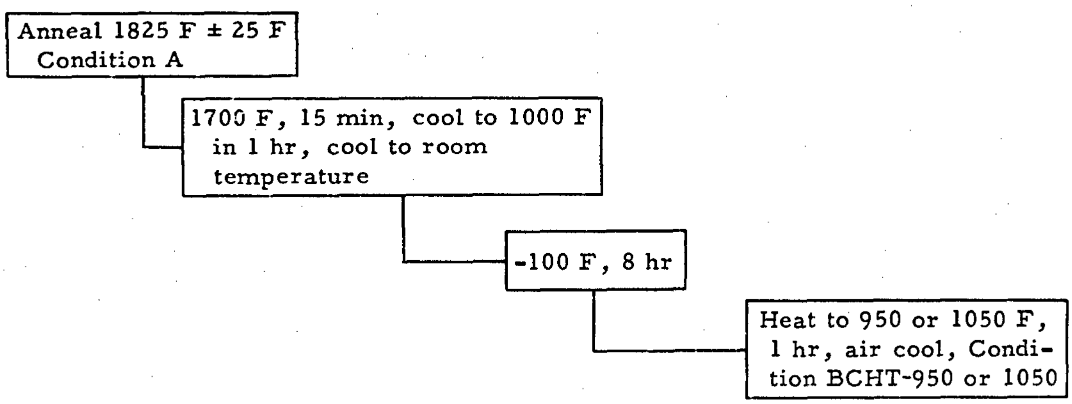


FIGURE 5. HEAT-TREATING SCHEDULES FOR PH13-8Mo

TABLE 16. TYPICAL ROOM-TEMPERATURE TENSILE PROPERTIES OF PH13-8Mo[a]

(3 x 8-in. billet.)[b]

Condition	Test Direction	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Elongation in 4 x Diameter, %	Reduction in Area, %	Impact Charpy V, ft-lb	Hardness, Rockwell
A	Longitudinal	161	101	15.6	66.6	--	C 35
H-950	Longitudinal	214	188	15.9	63.3	18	C 46
	Transverse	214	189	14.1	63.2	--	
	Short transverse	217	192	15.0	65.2	15	
H-1000	Longitudinal	217	200	14.1	64.1	50	C 46
H-1050	Longitudinal	195	187	14.7	68.9	110	C 43
	Short transverse	--	--	--	--	73	
H-1100	Longitudinal	173	162	17.5	72.2	135	C 39

(a) Double vacuum-melted heat.
(b) All test specimens taken from intermediate location in the billet.

TABLE 17. TENSILE PROPERTIES FOR PH13-8Mo IN THE BRAZE CYCLE AND IN THE SRH-950 CONDITIONS[a]

(3 x 8-in. cross section.)[b]

Condition	Test Direction	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Elongation in 4 x Diameter, %	Reduction in Area, %	Impact Charpy V, ft-lb	Hardness, Rockwell
BCHT-950[c]	Longitudinal	226	207	13.1	65.7	22	C 47
	Transverse	223	200	14.8	62.8	--	
	Short transverse	224	199	17.0	60.5	--	
BCHT-1050[c]	Longitudinal	212	206	14.1	67.3	96	C 45
	Transverse	209	201	13.1	63.8	--	
	Short transverse	202	194	15.0	62.3	--	
SRH-950[d]	Longitudinal	225	204	13.5	65.9	28	C 47
	Transverse	225	202	13.1	62.8	--	
	Short transverse	225	203	11.0	52.5	--	

(a) Double vacuum-melted heat.
(b) All test specimens taken from intermediate location in the billet.
(c) 1700 F for 15 min, cool to 1000 F in 1 hr, + -100 F for 8 hr, 950 or 1050 F for 1 hr, air cool.
(d) 1700 F for 1 hr, air cool, -100 F for 8 hr, + 950 F for 1 hr, air cool.

TABLE 18. PRECRACKED CHARPY V-NOTCH IMPACT TESTS OF DOUBLE VACUUM-MELTED PH13-8Mo

(3 x 8-in. cross section.)[a]

Condition	Test Direction	Depth of Fatigue Crack, in.	Impact, ft-lb	Work/Area, in./lb/in.^{2}
H-950	Longitudinal	0.0617	6.5	780
		0.0677	6.5	800
	Short transverse	0.0498	5.0	574
		0.0498	6.0	689
H-1050	Longitudinal	0.0782	57.5	7380
		0.0590	72.5	8600
	Short transverse	0.0657	58.5	7160
		0.0485	68.5	8130

(a) All test specimens taken from intermediate location in the bar.

TABLE 19. STRESS-CORROSION DATA OBTAINED ON PH13-8Mo

Alloy	Test Direction	Condition	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Exposure Stress, ksi	Average Days to Failure
PH13-8Mo	Transverse	BCHT-900	248	223	201	487
	Longitudinal	BCHT-900	235	215	193	396

15-5PH

15-5PH[4,5] is a martensitic precipitation-hardenable stainless steel developed by the Armco Steel Corporation to provide a high-strength material with good short-transverse centerline ductility in large cross sections. This is accomplished through consumable-electrode vacuum-arc remelting practice to minimize gross center segregation effects, and by composition adjustment to produce a microstructure free of delta ferrite. Nominal chemical composition of 15-5PH is as follows:

Element	Percent
C	0.07 max
Mn	1.00 max
P	0.04 max
S	0.03 max
Si	1.00 max
Cr	14.00-15.50
Ni	3.50-5.50
Cu	2.50-4.50
Cb + Ta	0.15-0.45.

Physical Metallurgy

The microstructure of 15-5PH is free of delta ferrite at the solution-annealing temperature due to its reduced chromium content and slightly increased nickel content. With this chemical balance, the M_s-M_f temperature range is above room temperature, and transformation to martensite occurs on oil quenching or air cooling. Subsequent reheating to the aging temperatures precipitates submicroscopic copper compounds that significantly increase the strength and hardness.

Heat Treatment

15-5PH is solution annealed by heating at 1900 F for 30 minutes followed by an air cool or an oil quench to obtain Condition A. Maximum tensile-strength properties are obtained by precipitation hardening at 900 F for 1 hour. Higher ductility and toughness values at lower strengths can be obtained by overaging for 4 hours at temperatures ranging from 925 to 1150 F. The standard heat treatments for 15-5PH steel are outlined in Figure 6.

Air is a satisfactory furnace atmosphere for heat treating 15-5PH. Fuel-fired furnaces, where combustion products might contaminate the workpiece surfaces, should be avoided.

Mechanical Properties

Typical longitudinal-direction mechanical properties of 15-5PH in all standard heat-treat conditions are shown in Table 20. The mechanical

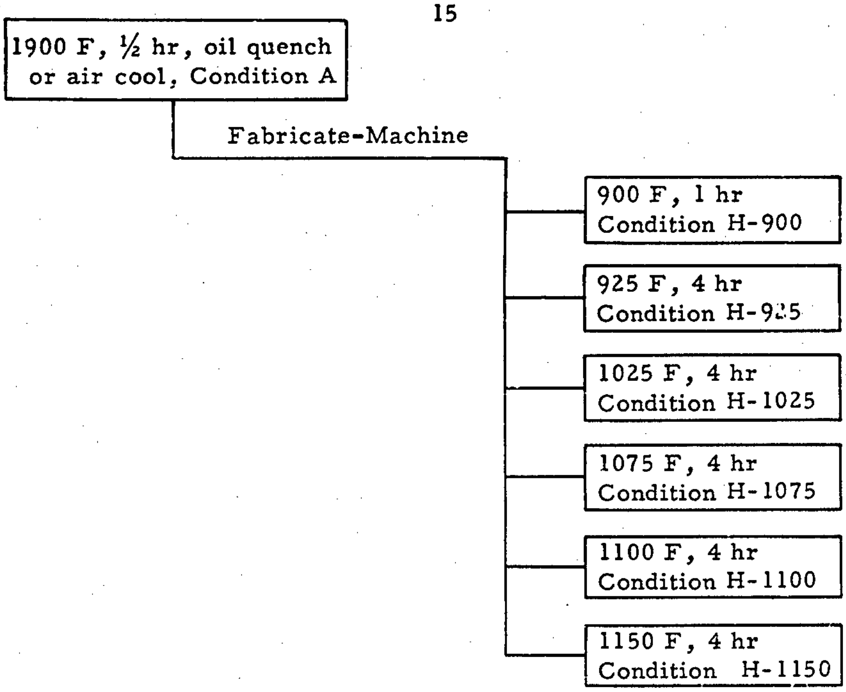


FIGURE 6. HEAT TREATMENT OF 15-5PH

properties in the transverse direction at intermediate and center line locations of vacuum-arc remelted material are listed in Table 21. The shear strength in torsion of 15-5PH in four heat-treated conditions is shown in Table 22. The strength in double shear for the H-900 condition is shown in Table 23.

Physical Properties

Table 24 lists physical properties that have been determined for 15-5PH steel.

Fabrication and Cleaning

15-5PH steel in Condition A is martensitic, has a maximum hardness of 38 Rockwell C, and is readily machinable. Finish-machined parts should be degreased and water rinsed to remove all traces of cutting oils or coolants prior to final hardening. The heat discoloration produced by the low-temperature aging treatment may be removed by short-time immersion in a 10%HNO_3-2%HF acid pickle. Immersion time should not exceed 3 to 5 minutes, to prevent etching and excessive metal removal. Completed parts should be passivated in 40 to 60 percent HNO_3 solution.

Welding

15-5PH may be welded by the arc and resistance methods currently used on austenitic stainless steels. W17-4PH electrodes are recommended for filler material. Preheating is not required for welding, and resolution annealing is not necessary. Weld-joint strength nearly equal to the base-metal properties can be obtained by postweld precipitation hardening.

Corrosion

The general corrosion resistance of 15-5PH is comparable to that of 17-4PH. Welded stress-corrosion specimens of 15-5PH plate in the H-1025 and H-1100 conditions did not crack during 6 months exposure at the Kure Beach, North Carolina, 80-foot lot, while under stress equal to 90 percent of the room-temperature yield strength.

Availability and Usage

15-5PH stainless steel is produced as air- or vacuum-melted bar, wire, plate, and billet. Its high strength, good transverse toughness, and forgeability make it particularly suited for parts of large cross section that will be loaded in the transverse directions.

17-4PH Sheet and Strip

17-4PH[6] is a martensitic precipitation-hardenable stainless steel developed by the Armco Steel Corporation. This alloy, available since about 1950 in bar, wire, forgings, and castings, is widely used in many applications due to its machinability, high mechanical properties, good corrosion resistance, and one-stage low-temperature heat treatment. Armco now produces the 17-4PH composition as a sheet and strip product. The chemical composition limits are unchanged and are as follows:

Element	Percent
C	0.07 max
Mn	1.00 max
P	0.04 max
S	0.03 max
Si	1.00 max
Cr	15.50-17.50
Ni	3.00-5.00
Cu	3.00-5.00
Cb + Ta	0.15-0.45.

TABLE 22. SHEAR STRENGTH OF 15-5PH IN TORSION

	Condition			
	H-900	H-1025	H-1075	H-1150
Unit Shear Strength, ksi, at elastic limit	98	86.2	67.5	42.5
Ultimate Shear Strength, ksi (modulus of rupture)	171	141	135	124

TABLE 20. TYPICAL MECHANICAL PROPERTIES OF 15-5PH[a]

	Condition					
	H-900	H-925	H-1025	H-1075	H-1100	H-1150
Ultimate Tensile Strength, ksi	200	190	170	165	150	145
0.2% Yield Strength, ksi	185[b]	175	165	150	135	125
Elongation, % in 2 in. or 4 x diameter	14.0	14.0	15.0	16.0	17.0	19.0
Reduction of Area, %	50.0	54.0	56.0	58.0	58.0	60.0
Hardness						
Brinell	420	409	352	341	332	311
Rockwell	C 44	C 42	C 38	C 36	C 34	C 33
Impact, Charpy V-Notch, ft-lb	20	25	35	40	45	50

(a) Longitudinal direction, intermediate location; air melted or consumable-electrode vacuum-arc remelted.
(b) Compressive yield strength for Condition H-900 is 178,000 psi.

TABLE 23. SHEAR STRENGTH OF 15-5PH IN DOUBLE SHEAR[a]

Condition	Specimen Size (Radius), in.	Shear Strength, ksi	Tensile Strength, ksi	Shear/Tensile Ratio, %
H-900	5/8	133	192	69.3
H-900	1/2	130	192	67.5
H-900	1/4	133.5	192	69.5

(a) Test specimens came from a single heat of typical composition. Duplicate specimens were tested for each size. Shear tests were conducted in accordance with the National Aircraft Standard No. 498.

TABLE 21. TYPICAL MECHANICAL PROPERTIES OF 15-5PH[a]

	Condition											
	H-900		H-925		H-1025		H-1075		H-1100		H-1150	
	I[b]	C[c]	I	C	I	C	I	C	I	C	I	C
Ultimate Tensile Strength, ksi	200	200	190	190	170	170	165	165	150	150	145	145
0.2% Yield Strength, ksi	185	185	175	175	165	165	150	150	135	135	125	125
Elongation, % in 2 in. or 4 x diameter	10.0	10.0	11.0	11.0	12.0	12.0	13.0	13.0	14.0	14.0	15.0	15.0
Reduction of Area, %	30.0	30.0	35.0	35.0	42.0	42.0	43.0	43.0	44.0	44.0	45.0	45.0
Hardness												
Brinell	420	420	409	409	352	352	341	341	332	332	311	311
Rockwell	C 44	C 44	C 42	C 42	C 38	C 38	C 36	C 36	C 34	C 34	C 33	C 33
Impact, Charpy V-Notch, ft-lb												
Notch Axis Longitudinal	7	--	17	--	27	--	30	--	30	--	50	--
Notch Axis Transverse	8	--	12	--	25	--	25	--	25	--	45	--

(a) Transverse direction, intermediate and center location; consumable-electrode vacuum-arc remelted.
(b) Intermediate location
(c) Center location.

TABLE 24. PHYSICAL PROPERTIES OF 15-5PH

	Condition			
	A	H-900	H-1075	H-1150
Density,				
grams/cu cm	7.78	7.80	7.80	7.82
lb/cu in.	0.280	0.282	0.283	0.284
Electrical Resistivity, Micohm-cm	98	77	--	--
Mean Coefficient of Expansion 10^{-6} in./in./F				
-100/70 F	--	5.8	--	6.1
70/200 F	6.0	6.0	6.3	6.6
70/400 F	6.0	6.0	6.5	6.9
70/600 F	6.2	6.3	6.6	7.1
70/800 F	6.3	6.5	6.8	7.2
70/900 F	--	--	--	7.3
Thermal Conductivity, Btu/hr/sq ft/in./F				
300 F	--	124	--	--
500 F	--	135	--	--
860 F	--	156	--	--
900 F	--	157	--	--
Specific Heat Btu/lb/F				
32/212 F	0.11	0.10	--	--
Tension Modulus x 10^{-6} psi[(a)]	--	28.5	--	--
Torsion Modulus x 10^{-6} psi	--	11.2	10.0	10.0

(a) The modulus of elasticity of 15-5PH at elevated temperature can be conveniently expressed as percent of room temperature modulus. At temperatures ranging from room to 600 F this material showed the following:

Temperature, F	Modulus of Elasticity (percent of room temperature modulus)
72	100.0
100	99.6
200	97.8
300	96.3
400	94.7
500	93.0
600	91.4

Poisson's Ratio in all hardened conditions is 0.272.

Physical Metallurgy

17-4PH at the solution-annealing temperature, 1900 F, is primarily austenite with the precipitation-hardening element, copper, in solution. A small percentage of delta ferrite may be present, depending on the composition balance. On cooling from the solution-annealing temperature, the M_s-M_f temperature range is 270 to 90 F. At room temperature, the structure is a low-carbon low-strength martensite supersaturated with copper. On reheating, precipitation of an unidentified copper phase causes maximum hardening at about 875 F.

Heat Treatment

The recommended solution-annealing temperature for 17-4PH is 1900 F ± 25 F for 30 minutes. Annealing at lower temperature results in reduced strength due to less dissolved carbon and copper in the austenite. High annealing temperature causes greater solution of carbon and, on quenching, austenite is retained resulting in lower yield strength. Transformation of 17-4PH occurs on air cooling to room temperature. Sections up to 3 inches may be oil quenched. Cross sections 3 inches and over should be air cooled or slow cooled to prevent cracking due to the strains developed by the austenite-martensite volume change. The highest strength for 17-4PH is obtained by aging 1 hour at 900 F, Condition H-900. Overaging for 4 hours at temperatures from 925 to 1150 F results in improved ductility and impact values, with lower tensile strengths. An outline of the heat-treat procedure for 17-4PH is shown in Figure 7.

Air is a satisfactory furnace atmosphere for heat treating 17-4PH. Salt-bath heat treatment is not recommended in order to avoid possible carburization or intergranular attack. Dissociated ammonia should not be used because of the possibility of nitriding part surfaces.

Mechanical Properties

Typical tensile properties of 17-4PH sheet and strip in the annealed condition and in five standard heat-treated conditions are shown in Table 25. Sheet and strip cold flattened by stretcher leveling or rolling will have slightly higher strength and lower ductility, as shown in Table 26. The tensile-strength properties of 17-4PH in Condition H-900 at subzero and at elevated temperatures are given in Table 27.

Physical Properties

Physical properties of 17-4PH steel are given in Table 28.

TABLE 25. TYPICAL MECHANICAL PROPERTIES OF 17-4PH SHEETS AND STRIP (NOT COLD FLATTENED)

Property	Condition					
	A	H-900	H-925	H-1025	H-1075	H-1150
Ultimate Tensile Strength, ksi	155	200	190	170	165	145
0.2% Yield Strength, ksi	120	180	175	160	155	135
Elongation, % in 2 in.	7.0	9.0	10.0	10.0	10.0	13.0
Hardness, Rockwell	C 35	C 45	C 43	C 39	C 38	C 34

TABLE 26. TYPICAL MECHANICAL PROPERTIES OF 17-4PH SHEETS AND STRIP (COLD FLATTENED)

Property	Condition A	H-900	H-925	H-1025	H-1075	H-1150
Ultimate Tensile Strength, ksi	160	210	200	185	175	160
0.2% Yield Strength, ksi	145	200	195	170	165	150
Elongation, % in 2 in.	5.0	7.0	8.0	8.0	8.0	11.0
Hardness, Rockwell	C 33	C 45	C 43	C 38	C 37	C 33

TABLE 27. TENSILE PROPERTIES OF 17-4PH IN CONDITION H-900 AT SUBZERO AND AT ELEVATED TEMPERATURES

Test Temperature, F	Ultimate Strength, ksi	0.2% Yield Strength, ksi
-320	263	243
-80	218	194
-40	209	186
70	198	177
400	181	161
600	175	153
800	162	140
1000	119	106

TABLE 28. PHYSICAL PROPERTIES OF 17-4PH

Density	0.28 lb/in.^{3}
Modulus of Elasticity (E)	28.5 x 10^6 psi
Specific Heat (32-212 F)	0.11 Btu/lb/F
Thermal Conductivity (212 F)	9.8 Btu/hr/ft^2/ft/F
Coefficient of Thermal Expansion	
32 to 212 F	6.0 in./in./F x 10^{-6}
32 to 600 F	6.3 in./in./F x 10^{-6}
32 to 800 F	6.5 in./in./F x 10^{-6}

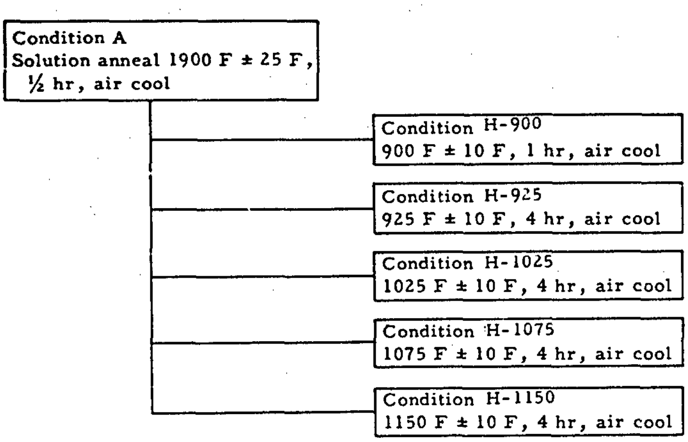


FIGURE 7. HEAT TREATMENT OF 17-4PH STEEL

Fabrication and Cleaning

Cold forming of 17-4PH in the annealed condition must be limited to relatively mild operations. Formability can be improved by overaging to increase ductility and bend properties. Minimum-bend radii for 17-4PH sheet and strip, expressed as a function of material thickness, are shown in Table 29. If parts are formed in the overaged condition but require higher strengths, they must be re-solution treated at 1900 F and subsequently aged at the appropriate temperature to obtain the properties desired. The mechanical properties and depth of draw by Olsen cup test for annealed, heat treated, and overaged conditions are shown in Table 30. In practice, the forming method and part configuration must be considered in order to select the material properties most suitable for part fabrication at room temperature.

17-4PH also can be hot formed while cooling from the 1900 F solution-annealing temperature. Such forming should take place at temperatures above the M_s point, with 700 to 900 F the preferred range. The mechanical properties of 17-4PH tested at temperature on cooling from 1900 F are shown in Table 31. The results of room-temperature tensile tests on 17-4PH, stretched during cooling from the solution annealing temperature (Table 32), show the mechanical properties expected from this hot-forming method.

Grit blasting is the recommended method for removing scale formed at the 1900 F solution-annealing temperature. Scale may also be removed by conditioning in caustic permanganate at 160 to 180 F for 1 hr followed by dipping 2 to 5 min in 10%HNO_3-2%HF acid pickle. High-temperature, fused-salt scale-softening baths should not be used because they will age harden 17-4PH steel. The heat tint developed during the low-temperature precipitation-hardening treatments may be removed by a 2- to 5-min immersion in the standard nitric-hydrofluoric acid stainless-steel pickle.

Welding

17-4PH may be welded by most of the methods used for austenitic stainless steels. Preheating is not required, and, when 17-4PH filler metal is added, full joint strength can be obtained by aging after welding.

Corrosion

17-4PH has exhibited excellent corrosion resistance in many industrial and marine applications. It also has good stress-corrosion resistance when precipitation hardened at 1000 F or higher, and is oxidation resistant over its usable temperature range.

TABLE 29. MINIMUM-BEND PROPERTIES FOR 17-4PH

	Minimum-Bend Radius(a)					
	90°		135°		180°	
Condition	L	T	L	T	L	T
A	3T	4T	3T	5T	6T	9T
H-900	3T	4T	3T	6T	5T	9T
H-925	2T	4T	3T	6T	5T	9T
H-1025	2T	4T	3T	6T	4T	7T
H-1075	2T	4T	3T	4T	4T	7T
H-1150	2T	2T	2T	3T	4T	6T

(a) Expressed as function of sheet thickness. Minimum radius to make indicated bend with no fissuring when viewed under 8-10X magnifying glass.

Availability and Usage

Sheet and strip of 17-4PH steel are now available in the solution-annealed condition. Fabrication of complex parts may be difficult because of the high strength and the low bend properties and ductility of this alloy in Condition A. Hot forming or forming in an overaged condition may be necessary to manufacture some parts. Details formed in Condition A, or assemblies welded in Condition A, may be hardened by aging only. If high strength is required for parts formed in overaged conditions, they must be re-solution annealed at 1900 F before precipitation hardening.

Custom 455

Custom 455[7], developed by the Carpenter Steel Company, is one of the new low-carbon martensitic precipitation-hardenable stainless steels. It exhibits good room- and elevated-temperature tensile properties and good corrosion resistance in fully heat-treated conditions. The alloy is completely martensitic in the annealed

TABLE 30. ROOM-TEMPERATURE TENSILE PROPERTIES AND OLSEN-CUP DRAW DEPTHS OF 17-4PH ANNEALED, HEAT TREATED AND OVERAGED

Condition	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Percent Elongation in 2 In.	Hardness, R_c	Olsen Cup Draw, in.
A	110.0	156.5	6.7	33.0	0.330
H-900 (1 hr)	181.7	200.5	10.5	44.5	0.250
H-1150 (4 hr)	132.8	144.5	13.2	32.5	0.330
H-1300 (2 hr)	103.5	142.7	9.5	30.0	0.248
H-1400 (2 hr)	117.0	148.5	8.7	32.0	0.309
H-1500 (2 hr) + 1150 (4 hr)	108.5	131.0	16.2	27.5	0.327

TABLE 31. MECHANICAL PROPERTIES OF 17-4PH OBTAINED AT TEMPERATURE DURING COOL DOWN FROM 1900 F

Test Temperature, F	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Percent Elongation in 2 In.	Hardness - R_c	
				Cooled to Room Temperature	Aged at 900 F
400	20.2	143.5	8	35	43
500	23.0	125.5	24	37	44
550	25.7	122.8	27	36.5	43.5
600	25.1	122.0	26.5	37	44
650	25.6	108.0	42.5	36.5	44
700	25.7	101.2	51	37	44
750	24.9	87.2	63	36.5	43.5
800	24.6	94.2	85	37	43
900	24.1	63.0	43	35	42.5

TABLE 32. ROOM-TEMPERATURE PROPERTIES OF 17-4PH STRETCHED AT VARIOUS TEMPERATURES ON COOLING FROM THE SOLUTION-TREATMENT TEMPERATURE

Hot-Forming Temperature, F	Percent Stretch in 2 In.	Aging Temperature, F (4 hr)	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Percent Elongation in 2 In.
500	9	900	198.0	202.2	9
650	16	900	168.7	190.8	9
650	20	900	171.8	190.5	9
650	33.5	None	133.6	162.4	6
650	35	900	181.4	194.6	7.5
650	35	1050	155.0	160.0	7.5
800	22	900	166.6	178.4	11
800	42	None	116.0	155.8	7
800	47.5	900	176.0	190.0	8
Standard H-900			173.8	195.0	11

condition, and it requires only a low-temperature precipitation treatment to obtain high strengths. Additional strengthening can be accomplished by cold working the annealed material and subsequently aging it. The nominal composition of Custom 455 is as follows:

Chemical	Percent
C	0.03 max
Mn	0.50 max
Si	0.50 max
Cr	11.00-13.00
Ni	7.00-10.00
Ti	0.90-1.40
Cb + Ta	0.25-0.50
Cu	1.00-3.00
B	0.005 max
Fe	Balance

Physical Metallurgy

The chemical balance of Custom 455 is adjusted to remain austenitic and free of delta ferrite at annealing temperatures up to 1800 F. The M_s-M_f range is above room temperature, resulting in a wholly martensitic structure when water quenched. Copper and titanium are added to the composition to provide strengthening by precipitation of intermetallic compounds on reheating to the aging temperature.

Heat Treatment

Custom 455 is heat treated by austenitizing at 1500 F for 30 min, water quenching or air cooling to room temperature depending on section size, and aging at 900 to 1050 F for 4 hr. It is desirable to heat thick cross sections 1 hr at 1800 F and water quench prior to the above processing to obtain improved transverse properties. This treatment also will produce the lowest hardness, in the annealed condition, approximately R_c 30, in all product forms. The recommended heat-treat procedures are outlined in Figure 8.

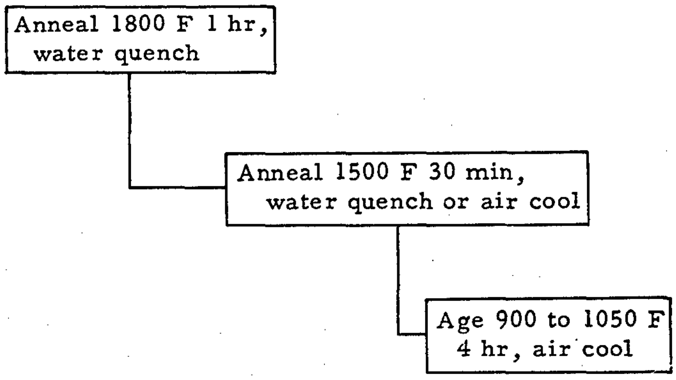


FIGURE 8. HEAT TREATMENT OF CUSTOM 455

Air is a suitable furnace atmosphere for heat treating Custom 455. The usual precautions concerning surface contamination from the combustion products of fuel-fired furnaces, controlled atmospheres, and salt baths should be observed. Heat treatment can be done in inert gas or vacuum, if adequate quench rates can be realized.

Mechanical Properties

Some typical room-temperature mechanical properties for Custom 455 billet, bar, and strip in the annealed and several aged conditions are shown in Table 33. The effects of cold work, and cold work plus aging, on the tensile properties of sheet product are displayed in Table 34. Short-time elevated-temperature tensile properties for heat-treated billet and bar are shown in Table 35. The mechanical properties of bar product in the 900 F-age, and 1000 F-age conditions tested at cryogenic temperatures are shown in Table 36.

Physical Properties

Some physical properties have been determined for Custom 455 in the precipitation-hardened condition. The density of the alloy is 0.282 lb/cu in., and the modulus of elasticity in tension is reported to be 27 x 10^6 psi. Linear

coefficient of thermal expansion up to 1150 F is shown in Table 37.

Fabrication and Cleaning

Annealed Custom 455 bar and billet may be machined to final dimensions prior to aging. Rigid set-up, adequate coolant, 0.004-in. feed, and a speed of 50 surface ft/min are recommended for machining (turning). Precipitation heat treatment causes a contraction of approximately 0.001 in./in. Only extremely close-tolerance parts will require machining after final hardening. Machined parts should be degreased and water rinsed before aging. After heat treatment, parts should be pickled 3 to 5 min in 10%HNO_3-2%HF, then passivated in 40 to 60 percent HNO_3.

Custom 455 sheet can be formed in the annealed condition. Considerable power may be required because of the high-yield strength of the steel in the annealed condition. Additional information, such as minimum-bend diameter, springback, and uniform-elongation values should be determined to aid in designing formed parts. Although Custom 455 has a relatively low work-hardening rate, intermediate annealing may be required to fabricate deep-drawn or complex

TABLE 33. TYPICAL ROOM-TEMPERATURE MECHANICAL PROPERTIES OF CUSTOM 455

Form	Condition(a)	Test Direction	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	K_t = 10 Notch Tensile, ksi	Elongation,(b) % in 4 x diameter	Reduction of Area, %	Hardness, Rc	Impact Charpy-V, ft-lb
9 x 9-in. billet	Annealed	Longitudinal	118	145	230	17.0	68	30	35
		Transverse	136	145	220	13.5	54	30	29
	950 F age	Longitudinal	223	237	306	11.0	46	49	10
		Transverse	225	237	285	6.5	26	49	5
	1050 F age	Longitudinal	180	200	300	16.0	58	43	35
		Transverse	182	197	270	10.5	31	43	14
13/16-in. diameter bar	Annealed	Longitudinal	125	156	250	14.0	71	35	90
	900 F age	Longitudinal	245	257	301	12.0	47	51	12
	950 F age	Longitudinal	235	244	332	13.0	53	50	14
	1000 F age	Longitudinal	198	212	314	18.0	60	45	28
0.060 in. strip	Annealed	Longitudinal	132	163	--	13.5	--	34	--
		Transverse	--	172	--	13.0	--	34	--
	950 F age	Longitudinal	248	252	--	11.0	--	50	--
		Transverse	--	264	--	8.5	--	50	--

(a) Heat-treat conditions: billet - annealed, 1800 F, 1 hr, water quenched plus 1500 F, 1/2 hr, water quenched: 950 F age and 1050 F age, annealed plus 4 hr at age temperature; bar - annealed, 1500 F, 1/2 hr, water quenched; 900 F age, 950 F age, and 1000 F age, annealed + 4 hr at age temperature; strip -annealed, 1500 F, 5 min, air cooled; 950 F age, annealed + 4 hr at age temperature..

(b) Strip elongation percent in 1 in.

TABLE 34. EFFECT OF COLD WORK AND AGING ON THE TENSILE PROPERTIES OF CUSTOM 455 STRIP

	Cold Work Only			Cold Work + 4-Hr 900 F Age		
Cold Work, %	Ultimate Tensile Strength, ksi	0.2 % Yield Strength, ksi	Elongation, % in 1 in.	Ultimate Tensile Strength, ksi	0.2 % Yield Strength, ksi	Elongation, % in 1 in.
10	165	150	15	265	262	10
20	170	160	14	268	266	9
30	175	167	14	272	269	9
40	181	175	12	275	272	8
60	190	185	9	282	279	7
80	200	200	8	289	284	5

TABLE 35. ELEVATED TEMPERATURE TENSILE PROPERTIES OF CUSTOM 455

Form	Condition[a]	Test Temperature, F	Ultimate Tensile Strength, ksi	0.2 % Yield Strength, ksi	Elongation, % in 4 x diameter	Reduction of Area, %
9 x 9-in. Billet	950 F age	Room	237	223	11	46
		700	187	180	8	37
		800	177	170	9	37
		900	163	155	11	46
		1000	136	128	14	55
13/16 in. Diameter Bar	900 F age	Room	257	245	12	47
		600	215	209	12	57
		800	186	175	14	65
		1000	140	133	20	77

(a) Billet heat treatment - 1800 F, 1 hr, water quenched plus 1500 F, 1 hr, water quenched plus 950 F, 4 hr air cooled.
Bar heat treatment - 1500 F, 1/2 hr, water quench plus 900 F, 4 hr, air cooled.

TABLE 36. MECHANICAL PROPERTIES OF CUSTOM 455 BAR AT CRYOGENIC TEMPERATURES

Condition[a]	Test Temperature, F	Ultimate Tensile Strength, ksi	Notch Tensile Strength, ksi K_t = 10 notch	Elongation, % in 4 x diameter	Reduction of Area, %	Impact Charpy V, ft-lb
900 F age	-100	273	272	10	45	3
	-300	296	100	9	33	1
1000 F age	-100	226	330	14	58	18
	-300	251	272	14	53	7

(a) Heat-treat condition: annealed 1500 F, 1/2 hr, water quenched and aged 4 hr at 900 F or 1000 F.

parts. Wet-grit blasting is recommended to remove the scale formed in annealing. Fused-salt scale conditioners that operate at 800 to 1000 F should not be used, since these temperatures will strengthen the alloy and defeat the purpose of the intermediate anneal. Boiling aqueous caustic permanganate scale conditioning followed by the HNO_3-HF pickle is a satisfactory scale-removal treatment. All parts should be passivated in 40 to 60 percent HNO_3 as the final processing step.

Welding

Custom 455 may be welded by the tungsten inert-gas method using filler metal of the same composition. Welded, annealed, and aged strip product has shown 100 percent joint efficiency, while annealed material welded and aged has shown 80 percent joint efficiency.

Corrosion

Custom 455 has good resistance to oxidation up to 1200 F. Limited corrosion tests have been conducted on this alloy. No rusting or pitting was observed after 14 days' exposure in 5% salt spray at 95 F. Tests in boiling 10% acetic acid and in 20% nitric acid at 200 F show this alloy to have better corrosion resistance than that of the standard 12% chromium stainless steels. Preliminary results of stress-corrosion tests in 20% salt spray at 95 F, and in boiling 6% sodium chloride plus 1-1/2% sodium dichromate indicate that the alloy has good resistance to stress-corrosion cracking.

Availability and Usage

Custom 455 is available as annealed bar and billet. Sheet or strip may be procured on order. It is applicable for parts requiring high strength and corrosion resistance at temperatures up to 900 F.

TABLE 37. COEFFICIENT OF THERMAL EXPANSION FOR CUSTOM 455

Temperature Range, F	Expansion, in./in./F x 10^6
68 to 212	6.05
68 to 392	6.05
68 to 572	6.44
68 to 752	6.60
68 to 932	6.78
68 to 1112	6.97
68 to 1150	6.97

AM-363

AM-363[8] is a low-strength martensitic stainless steel. It exhibits a small response to precipitation hardening, slightly increasing the yield strength and ductility. The strength level is approximately the same as 1/4- to 1/2-hard AISI Type 301. The alloy was developed by Allegheny Ludlum Steel Corporation to provide a low-cost, completely martensitic stainless steel. For this reason, the steel has a low alloy content, and residual-element limits are established on the basis of economical melting practice and raw-material costs. The nominal chemical composition of AM-363 is as follows:

Element	Percent
C	0.05 max
Mn	0.30 max
Si	0.15 max
Cr	11.00-12.00
Ni	4.00-5.00
Ti	10 x C min

Physical Metallurgy

AM-363 is completely austenitic at annealing temperatures of 1500 to 1700 F. The M_s-M_f range is 770 to 500 F. The structure of the alloy at room temperature is a low-carbon martensite. Only slight precipitation hardening occurs when the alloy is reheated at temperatures ranging from 800 to 1050 F.

Heat Treatment

Heat treatment for AM-363 consists of solution annealing at 1600 F for 5 min, air cooling to room temperature, and aging at 1000 F for 5 min.

Mechanical Properties

Aging or stress relieving at 1000 F raises the yield strength of annealed AM-363 approximately 10 percent, and improves ductility. Typical mechanical properties of 0.060-in.-thick sheet in this condition, tested at temperatures from -100 to 600 F, are shown in Table 38. The results indicate that AM-363 retains useful strength and toughness over this temperature range.

Physical Properties

Physical property data for AM-363 are shown in Table 39.

Fabrication and Cleaning

AM-363 sheet and strip have a low work-hardening rate and excellent bend properties. Transverse specimens can be bent 135 degrees around a radius equal to the sheet thickness without cracking. Parts may be formed at room temperature and require no thermal processing before or after fabrication. Finish-formed parts should be degreased and passivated before use.

Welding

Welding of AM-363 can be accomplished by any of the processes used for austenitic stainless steels. The low-carbon content and the addition of titanium prevent grain-boundary chromium carbide precipitation in weld-heat-affected zones. A comparison of the tensile properties of unwelded material and of joints in the as-welded condition is shown in Table 40.

Corrosion

Corrosion investigations have shown that AM-363 will withstand exposure to 5% salt spray at 95 F for 200 hr before the appearance of rust. The results of general corrosion tests in several chemical environments are shown in Table 41. Stress-corrosion test results (Table 42) show no failure after 155 days' exposure to 5% salt spray at stress levels approaching the 0.2-percent yield strength.

Availability and Usage

AM-363 is produced primarily as a sheet product. It is suitable for complex formed structural parts requiring mechanical properties equal to 1/2-hard austenitic stainless steel.

AM-362

AM-362,[8] developed by Allegheny Ludlum Steel Corporation, is a precipitation-hardenable martensitic stainless steel of intermediate alloy content. It is heat treatable to high strength, has good corrosion resistance, and may be machined in either the annealed or fully hardened conditions. The nominal composition of AM-362 is as follows:

Element	Percent
C	0.03
Mn	0.30
P	0.015
S	0.015
Si	0.20
Cr	14.50
Ni	6.50
Ti	0.80

Physical Metallurgy

The composition of AM-362 is balanced so as to be austenitic and free of delta ferrite at annealing temperatures from 1500 to 1650 F. The M_s-M_f temperature range is 510 to 320 F. The structure at room temperature is low-carbon martensite. Hardening is accomplished by precipitation of titanium compounds on reheating at 900 to 1100 F.

Heat Treatment

The recommended annealing treatment for AM-362 is 1 hr at 1500 F followed by air cooling to room temperature. Age hardening may be accomplished at various times and temperatures, ranging from 8 hr at 900 F to 1 hr at 1100 F, depending on the mechanical properties desired. An outline of the thermal processing of this alloy is shown in Figure 9.

Both the annealing and the aging treatments for AM-362 may be done in air-atmosphere furnaces. Fuel-fired open-muffle furnaces and controlled atmospheres such as dissociated ammonia should not be used, to avoid surface carburizing or nitriding. Salt-bath furnace heat treatment is not recommended.

Mechanical Properties

The range of room-temperature mechanical properties displayed by AM-362 for several aging temperatures and times is shown in Table 43. The tensile properties of material tested at subzero and at elevated temperatures after being aged at 900 F and at 1050 F are shown in Table 44. Room-temperature compression-test results for AM-362 in three aged conditions are listed in Table 45. Notched-to-unnotched tensile ratios at test temperatures from -320 to 800 F for round-bar specimens with K_t = 4.0 are listed in Table 46. The effects of cold drawing and aging on the tensile properties of AM-362 tubing and wire are shown in Tables 47 and 48, respectively. Typical mechanical properties of castings homogenized 1 hr at 2000 F, air cooled, and subsequently aged are shown in Table 49. Rotating-beam fatigue tests have been conducted on AM-362 specimens aged 3 hr at 1000 F. An endurance limit of 97,000 psi at 100 million cycles was reported.

TABLE 38. TYPICAL MECHANICAL PROPERTIES OF AM-363

Test Temperature, F	Yield Strength (0.02% Offset), ksi	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., %	Notch Tensile Strength,[a] ksi
		Longitudinal Tensile Properties (0.060-in. strip-annealed, aged, and pickled)			
-100	103.3	123.4	143.0	17.0	151.5
-50	93.5	117.6	135.3	15.0	147.0
Room	79.1	106.6	123.2	12.5	135.2
200	85.2	103.5	115.1	12.0	128.7
300	78.0	99.6	113.9	10.0	--
400	78.3	93.1	104.6	8.5	119.1
500	71.7	92.1	101.7	6.5	--
600	75.2	89.8	97.7	5.0	109.4
		Transverse Tensile Properties (0.060-in. strip-annealed, aged, and pickled)			
-100	110.1	130 4	146.7	10.0	159.6
-50	100.1	123.8	139.3	11.5	150.8
Room	89.7	112.3	125.3	11.5	141.7
200	89.1	108.5	118.2	9.5	134.1
300	79.3	103.9	113.5	6.5	--
400	77.6	101.3	108.4	6.0	121.5
500	73.3	97.1	105.5	4.5	--
600	79.5	96.4	102.8	3.0	108.6

(a) Diameter of root of notch is less than 0.001 in.

TABLE 39. PHYSICAL PROPERTIES OF AM-363

Density	0.281 lb/in.^{3}
Modulus of Elasticity (E)	
Longitudinal	27.9 x 10^6 psi
Transverse	27.5 x 10^6 psi
Modulus of Rigidity (G)	
Longitudinal	10.6 x 10^6 psi
Transverse	10.3 x 10^6 psi
Coefficient of Thermal Expansion	
68 to 212 F	5.7 x 10^{-6} in./in./F
68 to 572 F	6.1 x 10^{-6} in./in./F
68 to 932 F	6.3 x 10^{-6} in./in./F

TABLE 40. TENSILE PROPERTIES OF WELDED JOINTS IN AM-363 SHEET[a]

Condition	Type Test	Test Temperature, F	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., percent	Location of Fracture
Mill annealed	Unwelded, longitudinal	Room	106.5	123.0	12.5	--
Mill annealed	Unwelded, transverse	Room	112.0	125.0	11.5	--
As welded	Longitudinally welded	Room	109.0	137.5	11.0	--
As welded	Transversely welded	Room	112.5	124.5	10.5	Base metal

(a) Tungsten inert-gas weld with no filler metal added.

TABLE 41. CORROSION TESTS ON AM-363

Test Medium	Exposure Period, hr	Penetration, in./month
Boiling 25% nitric	5 to 48	0.0125
Boiling 20% phosphoric	24	0.0009
Boiling 60% acetic	24	0.034

TABLE 42. RESULTS OF STRESS-CORROSION TESTS OF AM-363

(5% salt spray)

Heat	Hardness	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Applied Stress, ksi	Result
55658	25 R_c	105.0	122.6	100.0	No cracking 155 days
55663	25 R_c	109.2	128.2	100.0	No cracking 155 days

TABLE 43. EFFECT OF AGING TEMPERATURE ON MECHANICAL PROPERTIES OF AM-362[a]

Aging Treatment (Plus Air Cool) F	hr	Hardness, Rockwell C	Yield Strength (0.02% Offset), ksi	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., percent	Reduction of Area, percent	Impact Strength, ft-lb
900	8	41	164	182	188	13	54	6
950	4	39	156	172	177	14	57	10
975	4	38	152	167	172	15	58	15
1000	3	37	150	160	165	16	60	30
1050	2	33	132	144	152	18	64	50
1150	1	30	90	115	140	21	68	80
Annealed		25	68	108	125	16	68	--

(a) Bar-tensile and Charpy-V-notched impact specimens were annealed at 1500 F for 1 hr, air cooled, aged at the indicated temperatures, and tested at room temperature.

TABLE 44. TENSILE PROPERTIES OF AM-362 AT SUBZERO AND ELEVATED TEMPERATURES AFTER VARIOUS AGING TREATMENTS[a]

Test Temperature, F	Yield Strength (0.02% Offset), ksi	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., percent	Reduction of Area, percent
		Aged at 900 F for 8 hr			
-100	180.0	200.0	208.0	12.0	47.0
Room	164.0	182.0	188.0	13.0	54.0
200	152.0	168.0	174.0	15.0	55.0
400	140.0	155.0	163.0	15.0	55.0
600	128.0	145.0	154.0	14.0	55.0
800	102.0	128.0	140.0	14.0	57.0
		Aged at 1050 F for 2 hr			
-320	185.0	200.2	208.0	16.0	48.0
-100	145.6	157.5	169.5	17.0	58.3
Room	128.6	140.3	152.0	18.0	61.0
200	120.9	132.3	144.9	18.0	61.7
400	113.3	123.2	134.6	18.0	62.0
1000	54.3	70.7	82.4	25.0	73.6
1200	9.0	22.4	46.8	52.0	92.5
1500	6.2	12.5	20.8	105.0	95.4

(a) The specimens were annealed at 1500 F for 1 hr, air cooled, aged, air cooled and tested at the indicated temperatures.

TABLE 45. COMPRESSIVE YIELD STRENGTH OF AM-362 AFTER VARIOUS AGING TREATMENTS[a]

Aging Treatment F	Aging Treatment Hr	Yield Strength (0.02% Offset), ksi	Yield Strength (0.2% Offset), ksi
900	8	170	187
975	4	152	168
1050	2	132	145

(a) One-in.-diam bars were annealed at 1500 F for 1 hr, air cooled, aged at the indicated temperatures, and tested in compression.

TABLE 46. EFFECT OF AGING TEMPERATURE ON THE NOTCHED TENSILE PROPERTIES OF AM-362[a]

Test Temperature, F	Notched-to-Unnotched Tensile Ratio of Samples Aged at 900 F 8 hr	975 F 4 hr	1050 F 2 hr
-320	--	--	0.71
-100	0.69	--	1.55
-50	0.88	--	1.53
Room	1.35	1.59	1.58
200	1.6	--	1.56
400	1.59	--	1.57
600	1.56	--	--
800	1.53	--	--

(a) Round-bar notched tensile tests were prepared from 1-in.-diam bar, annealed at 1500 F for 1 hr, air cooled and aged at the indicated temperatures. The tensile specimens had a K_t of 4.0.

TABLE 47. TENSILE PROPERTIES OF COLD-DRAWN AND AGED AM-362 TUBING

Outside Diam, in.	Wall Thickness, in.	Condition	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., percent
1.750	0.200	As hot extruded + 1500 F, 1 hr, AC	--	--	--
		+ 900 F, 8 hr, AC	172.0	180.5	15
1.615	0.154	Cold drawn 27.4% + 900 F, 8 hr, AC	185.0	186.0	8
1.350	0.094	Cold drawn 62% + 900 F, 8 hr, AC	187.0	200.0	7
1.000	0.059	Cold drawn 70% + 900 F, 8 hr, AC	--	205.0	10
0.987	0.041	Cold drawn 87% + 900 F, 8 hr, AC	206.0	206.0	11

TABLE 48. TENSILE PROPERTIES OF COLD-DRAWN AND AGED AM-362 WIRE

Wire Diam, in.	Cold Reduction, percent	Aging Treatment Temperature, F	Aging Treatment Time, hr	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Reduction of Area, percent
0.111	88	None	--	165	185	20
		800	4	210	225	25
		850	4	215	230	30
		900	4	210	225	45
		950	4	205	220	40
0.083	10	None	--	131	136	70
		900	4	192	194	58
	75	900	4	196	202	47
	89	900	4	201	205	50
0.009	80	None	--	210	235	--
		800	1	256	257	--
		850	1	250	251	--
		900	1	250	250	--
		950	1	240	240	--

TABLE 49. MECHANICAL PROPERTIES OF AM-362 CASTINGS[(a)]

Aging Treatment F	Aging Treatment hr	Hardness, Rockwell C	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., percent	Reduction of Area, percent
900	8	40	187	201	6	12
1050	2	34	160	166	10	28

(a) Castings homogenized at 2000 F, 1 hr, air cooled to room temperature, aged at the indicated temperature, and tested at room temperature.

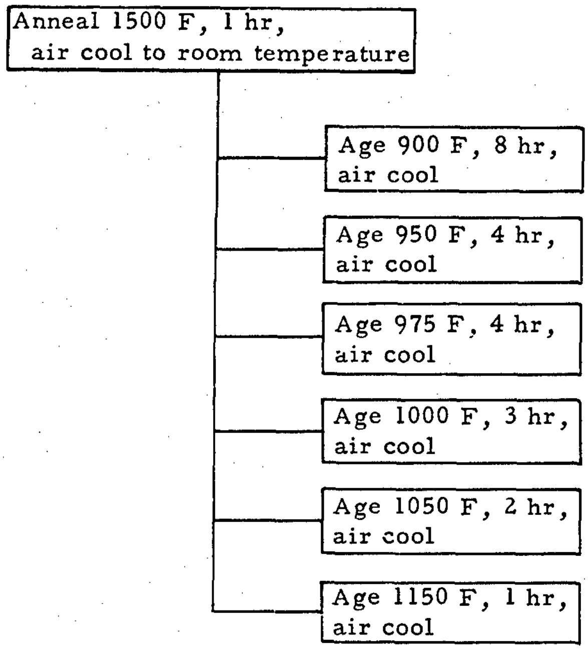


FIGURE 9. HEAT TREATMENT OF AM-362

Physical Properties

Physical-property data for AM-362 are listed in Table 50.

Fabrication and Cleaning

AM-362 can be fabricated into machined parts in either the annealed or aged conditions. When machined parts are in the annealed condition, they should be degreased and water rinsed before precipitation hardening. The discoloration from the low-temperature heat treatment may be removed by short-time immersion in 10%HNO_3-2%HF pickling solution. All parts should be passivated in 40 to 60 percent HNO_3 as a final surface treatment.

Welding

AM-362 may be welded by any of the methods currently used for austenitic stainless steels. Preheating or post-weld annealing is not required to prevent cracking or to improve weld-metal ductility. Aging after welding is necessary to increase strength. Filler wire of the same composition as the base metal may be used to TIG-weld AM-362 in sections up to 1/8 in. For multiple-pass welds in heavier sections, filler metal of lower titanium content is used for improved weld ductility at some sacrifice of strength. Mechanical properties of welded AM-362 strip, 0.031-in.-thick, using filler metal of 0.70% titanium content, are shown in Table 51. The mechanical properties of welded joints made in 1/2-in.-thick AM-362 plate with filler metal containing 0.40% titanium, are shown in Table 52.

Corrosion

The corrosion rates of AM-362 in several acid environments are listed in Table 53. Stress-corrosion tests have been conducted in 5% salt spray on transverse-strip specimens stressed from 75 to 95 percent of yield strength, and on longitudinal bar specimens stressed to 90 percent of yield strength. The test conditions and the results obtained are shown in Table 54.

Availability and Usage

AM-362 is primarily a bar product although sheet, plate, wire, and tubing have also been produced successfully. It can be used in applications requiring high strength and good corrosion resistance, such as in aircraft and missile structures, in hydraulic- and pneumatic-equipment components, and in the chemical-processing industry.

AFC-77

AFC-77[9,10] is a precipitation-hardenable martensitic stainless steel developed under Air Force contract by the Crucible Steel Company. It is capable of heat treatment to very high tensile strength and retains good mechanical properties up to about 1200 F. The alloy exhibits good corrosion and oxidation resistance. Preliminary evaluations indicate that good formability and weldability may be expected. The nominal composition of AFC-77 is as follows:

Element	Percent
C	0.15
Cr	14.5
Mo	5.0
V	0.5
Co	13.5
N	0.05

Physical Metallurgy

AFC-77 is chemically balanced to be austenitic and free of delta ferrite at elevated temperatures up to about 2000 F. To offset the ferrite-forming elements chromium, vanadium, and molybdenum in the composition, cobalt was selected as the austenite former that would have the least depressing effect on the M_s-M_f temperature range. On quenching or air cooling to room temperature, AFC-77 retains a relatively large amount of austenite. Refrigeration at -100 F followed by suitable double tempering progressively reduces the retained austenite in the structure to about 5 percent or less. During tempering, two precipitation reactions take place. Up to about 900 F, hardening is related to precipitation of carbides in the martensite. Above 1000 F, precipitation of Fe_2Mo Laves phase and the chi phase have been identified as the primary strengthening mechanisms.

TABLE 50. PHYSICAL PROPERTIES OF AM-362

Density	0.281 lb/in.^{3}
Modulus of Elasticity (E)	28.5 to 30.5 x 10^6 psi
Modulus of Rigidity (G)	11.0 to 11.8 x 10^6 psi
Coefficient of Thermal Expansion	
68 to 212 F	5.7 x 10^{-6} in./in./F
68 to 392 F	6.0 x 10^{-6} in./in./F
68 to 572 F	6.1 x 10^{-6} in./in./F
68 to 752 F	6.2 x 10^{-6} in./in./F
68 to 936 F	6.3 x 10^{-6} in./in./F
68 to 1112 F	6.4 x 10^{-6} in./in./F

TABLE 51. MECHANICAL PROPERTIES OF WELDED 0.031-IN.-THICK AM-362 STRIP(a)

Condition	Aged, F	Time, hr	Type of Test	Hardness, Rockwell C Base Metal	Weld	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., percent	Notched-to-Unnotched Tensile Strength Ratio(b)	Location of Fracture
Annealed 1500 F	--	--	Unwelded	28	--	114	140	3.0	1.06	--
As-welded	--	--	Transversely welded	28	28	116	146	3.0	--	Base metal
			Longitudinally welded	28	28	112	138	4.5	--	
	900	8	Unwelded	42	--	192	193	2.8	0.96	--
Welded +	900	8	Transversely welded	42	45	192	193	2.5	0.81	Base metal
Welded +	900	8	Longitudinally welded	42	45	190	195	5.2	--	
	1000	2	Unwelded	39	--	168	169	5.7	1.07	--
Welded +	1000	2	Transversely welded	39	43	170	172	4.5	1.07	Base metal
Welded +	1000	2	Longitudinally welded	39	43	171	176	6.5	--	--

(a) Filler wire contained 0.70 percent titanium
(b) ASTM edge-notched sheet tensiles, K_t = 15.

Heat Treatment

AFC-77 is austenitized at 1800 to 2000 F, air cooled or oil quenched to room temperature, refrigerated at -100 F, and double tempered at either 900 or 1100 F to obtain maximum tensile properties. The heat-treat schedule is outlined in Figure 10. Austenitizing and tempering temperatures may be adjusted to obtain improvement in stress-corrosion resistance, toughness, or other properties, at the cost of some reduction in strength.

Air furnaces may be used for austenitizing AFC-77. The scale formed can be removed by wet-grit blasting. Decarburization should not affect properties significantly because the alloy is relatively insensitive to changes in carbon content. Controlled atmosphere, such as dissociated ammonia, should be avoided to prevent surface contamination. Salt-bath heat treatment is not recommended. Vacuum or inert-gas atmosphere is not necessary for austenitizing, and may be impractical for cross sections requiring an oil quench.

AFC-77 can be tempered in air. The resulting heat tint can be removed by standard stainless-steel acid-pickle solutions.

TABLE 52. MECHANICAL PROPERTIES OF WELDED AM-362 1/2-IN. PLATE[a]

Condition: Aged, F	Condition: Time, hr	Type of Test	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., percent	Reduction in Area, percent	Notched-to-Unnotched Tensile-Strength Ratio[a]	Location of Fracture	Charpy V-Notch Impact, ft-lb
As-welded		Gas-tungsten arc-weld, 1/2-in.-thick all-weld-metal	102	122	18	67	1.60	Weld	75 97
		Transversely welded 1/2-in. plate	102	113	15	66		Base metal	
Welded + 900	8	1/2-in.-thick weld, all-weld-metal	132	134	18	56	1.64	Weld	26 59
Welded + 900	8	Transversely welded, 1/2-in. plate	128	136	15	69		Base metal	

(a) Filler wire contained 0.40 percent titanium.
(b) Round-bar notched tensiles, $K_t = 3.7$.

TABLE 53. CORROSION OF AM-362 IN ACID ENVIRONMENTS

Environment	Rate, in./month
Boiling nitric acid (25%)	0.0011
Boiling phosphoric acid (20%)	0.0002
Boiling acetic acid (60%)	0.0002
Concentrated sulfurous acid	0.00001
Sulfurous acid vapor	0.00003

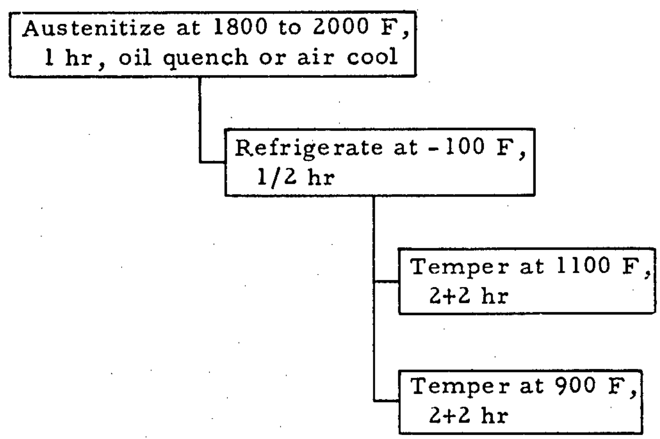


FIGURE 10. HEAT TREATMENT OF AFC-77

Mechanical Properties

Some typical room-temperature tensile strengths for AFC-77, austenitized at 1800, 1900, and 2000 F, refrigerated at -100 F, and subsequently tempered for 2+2 hr at 900 or 1100 F, are shown in Table 55.

The effects of tempering temperature on room-temperature mechanical properties of AFC-77 austenitized at 2000, 1900, and 1800 F are shown in Table 56.

The yield strength of AFC-77, austenitized at 2000 F and tempered at 1000 F, is considerably lower than the yield strength for either the 900 or 1100 F temper. The Crucible Steel Company investigated the effects of additional treatments in an effort to explain this condition. The results (Table 57) show that tempering at 900 F either before or after a 1000 F temper has no effect on the low-yield strength. However, tempering at 1000 F after tempering at 1100 F results in a yield strength typical for the 1100 F temper, indicating that the reaction is not reversible. Precipitation of carbides is not thought to be responsible because the hardness and ultimate tensile strength do not show a corresponding decrease. Austenite reversion was eliminated as a possible reason because refrigeration at -100 and -320 F, after the 1000 F temper, did not change the yield strength, and X-ray diffraction determinations revealed steadily decreasing austenite content with tempering-temperature increase from 900 to 1300 F. No conclusive explanation has been found for the low-yield strength anomaly.

The effects of short-time exposure at temperatures from -100 to 1200 F on the tensile properties of AFC-77 as tempered at 1100 F are shown in Table 58.

TABLE 54. STRESS-CORROSION TESTS OF AM-362 IN 5% SALT SPRAY

Material	Heat Treatment Temperature, F	Heat Treatment Time, hr	Applied Stress, ksi	Percent of 0.2% Yield Strength	Total Time	Condition
0.019 in. strip, transverse	900	8	190.0	90	Discontinued at 196 days, no cracks	1 small pit, 13 days
	1050	2	150.0	95	Discontinued at 196 days, no cracks	1 small pit, 13 days 1 small pit, 27 days
0.060 in. strip, transverse	900	8	137.0	75	Discontinued at 250 days, no cracks	No rust or pits
	975	4	125.0	75	Discontinued at 250 days, no cracks	No rust or pits
	1050	2	112.0	75	Discontinued at 250 days, no cracks	No rust or pits
1 in-diam bar, longitudinal	900	8	169.5	90	Discontinued at 140 days, no cracks	No rust, scattered small pits
	975	4	155.3	90	Discontinued at 140 days, no cracks	No rust, scattered small pits
	1050	2	136.7	90	Discontinued at 140 days, no cracks	No rust, scattered small pits

TABLE 55. ROOM-TEMPERATURE TENSILE PROPERTIES OF AFC-77[a]

	Austenitizing Temperature					
	2000 F		1900 F		1800 F	
Tempering Temperature, F	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi
1100	215	290	200	275	195	250
900	210	270	210	260	215	255

(a) Austenitized at indicated temperature 1 hr, oil quenched, refrigerated at -100 F 1/2 hr, tempered at the indicated temperature 2 plus 2 hr.

TABLE 56. EFFECT OF TEMPERING ON THE TENSILE PROPERTIES OF AFC-77[a]

Austenitizing Temperature, F	Tempering Temperature, F	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi: Smooth	Ultimate Tensile Strength, ksi: Notched[b]	Elongation, % in 1 in.	Reduction of Area, %
2000	600	171	258	362	22	58
	700	184	245	355	22	59
	800	200	253	374	21	58
	900	210	268	298	20	55
	1000	171	281	323	16	57
	1050	182	298	301	12	50
	1075	216	300	--	12	44
	1100	213	290	251	12	37
	1150	198	268	270	10	24
	1200	173	242	255	10	19
1900	700	183	242	--	18	56
	750	193	247	361	19	56
	800	196	248	331	19	53
	900	212	260	249	20	55
	1000	208	269	302	16	55
	1100	200	275	242	13	43
1800	700	184	239	336	15	47
	800	199	248	314	14	39
	900	215	256	299	16	48
	1000	219	258	265	16	49
	1100	195	251	306	15	48

(a) Austenitized 1 hr at the indicated temperature, oil quenched, refrigerated at -100 F 1/2 hr, tempered at the indicated temperature 2 plus 2 hr, tested at room temperature.
(b) Notched tensile specimen, K_t = 3.9.

The strength of AFC-77 can be increased by cold working and aging after austenitizing. The effect of various amounts of cold reduction followed by aging on the room-temperature tensile properties of AFC-77 sheet are shown in Table 59.

Limited tests have been conducted on AFC-77 sheet to determine the effects of elevated-temperature exposure under stress. The results listed in Table 60 show that the tensile properties of AFC-77 are relatively stable after exposure to 40,000 psi stress and 650 F temperature for 1000 hr. Toughness at -110 F, as measured by the edge-notched tensile test, was reduced by the exposure.

Investigation by the producer has shown that the best combination of ductility and spread between ultimate and yield strengths can be obtained by tempering at 500 F. Table 61 lists the tensile properties of AFC-77 austenitized at 2000, 1900, and 1800 F, and then tempered at 500 F for 2+2 hr, or 4 hr.

Crack-propagation tests using center-notch fatigue-cracked specimens were conducted on AFC-77 sheet after tempering at temperatures from 600 to 1100 F, and after cold rolling 5, 10, and 15 percent followed by tempering at 80. The results listed in Table 62 show that net fracture stress remains high for tempering temperatures up to 800 F, but that a drastic drop in the net fracture stress occurs for tempering temperatures of 900 to 1100 F.

Creep-rupture properties of AFC-77 were determined at 900 to 1200 F for various heat-treat conditions. Table 63 includes test results for air-melted sheet and air- and vacuum-melted bar austenitized at 2000 F and tempered at 900 or 1100 F. Table 64 lists the results for air-melted bar austenitized at 1800 F and tempered at 900, 1000, and 1100 F. In addition to these creep tests of AFC-77 heat treated to maximum strength, the effect of austenitizing temperature on the smooth- and notched-bar rupture life of specimens subsequently tempered at 1400 F was investigated. These results, shown in Table 65, indicated that maximum notched-bar creep-rupture life was obtained by austenitizing at 1900 F and over-tempering 2+2+2 hr at 1400 F. Additional tests of this heat treatment at exposure temperatures of 1000 and 1050 F are reported in Table 66. The tensile properties of AFC-77 in the 1400 F temper condition are shown in Table 67.

TABLE 57. EFFECTS OF ADDITIONAL TREATMENTS ON ROOM-TEMPERATURE TENSILE PROPERTIES OF AFC-77 AFTER 1000 F TEMPER[a]

Tempering Treatment	0.2% Offset Yield Strength, ksi	Tensile Strength, ksi	Elongation in 1 In., percent	Reduction of Area, percent
1000 F, 2+2 hr	180	283	18	57
1000 F, 2+2 hr; 900 F, 2+2 hr	177	294	16	55
900 F, 2+2 hr; 1000 F, 2+2 hr	170	284	16	55
1100 F, 2+2 hr; 1000 F, 2+2 hr	230	290	--[b]	--[b]
1000 F, 2+2 hr; -100 F, 1 hr	183	281	18	58
1000 F, 2+2 hr; -320 F, 1 hr	178	283	18	58

(a) Heat treatment: austenitized at 2000 F for 1 hr, oil quenched, and refrigerated at -100 F for 1/2 hr, and tempered as indicated.
(b) Fractured outside the gage length.

TABLE 58. EFFECT OF SHORT-TIME EXPOSURE AT VARIOUS TEMPERATURES ON THE TENSILE PROPERTIES OF AFC-77, AS TEMPERED AT 1100 F[a]

Test Temperature, F	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, % in 1 in.	Reduction of Area, percent
-100	233	310	12	36
-50	--	305	11	38
78	213	289	13	42
200	205	288	12	43
600	199	261	14	58
900	178	235	15	54
1000	164	214	15	50
1100	123	175	23	70
1200	81	121	26	74

(a) Austenitized 1 hr at 2000 F, oil quenched, refrigerated 1/2 hr at -100 F, tempered 2+2 hr at 1100 F.

TABLE 59. EFFECT OF COLD ROLLING ON THE TENSILE PROPERTIES OF AFC-77 SHEET[a]

Tempering Temperature, F	Cold Reduction, percent	0.2% Offset Yield Strength, ksi	Tensile Strength, ksi: Notched (K_t = 6.05	Tensile Strength, ksi: Unnotched	Elongation in 2 In., percent
700	0	174[b]	257[b]	230[b]	8[b]
700	5	233	285	247	5
700	8	248	281	259	4
800	0	204[b,c]	--	259[b,c]	22[b,c]
800	5	272	--	281	7
800	10	287	--	297	6
800	15	297	--	308	5
800	20	301	--	313	4
800	30	326	--	331	3
800	50	--	--	345	0
800	75	--	--	387	0

(a) Heat treatment: austenitized at 2000 F for 1/2 hr, oil quenched, cold rolled as indicated, and then tempered at indicated temperature for 2+2 hr.
(b) Specimen refrigerated -100 F for 1/2 hr after austenitizing.
(c) Bar specimen.

TABLE 60. THE EFFECT OF ELEVATED-TEMPERATURE EXPOSURE UNDER STRESS ON THE MECHANICAL PROPERTIES OF AFC-77 SHEET[(a)]

Test Temperature, F	Cold Reduction, percent	Tempering Temperature, F	Unexposed Specimens: 0.2% Offset Yield Strength, ksi	Unexposed: Tensile Strength, ksi, Edge Notched	Unexposed: Tensile Strength, ksi, Center Notched	Unexposed: Tensile Strength, ksi, Smooth	Unexposed: Elongation in 2 In., percent	Specimens Exposed Prior to Test at 650 F for 1000 hr Under 40,000 psi: 0.2% Offset Yield Strength, ksi	Exposed: Tensile Strength, ksi, Edge Notched	Exposed: Tensile Strength, ksi, Smooth	Exposed: Elongation in 2 In., percent
-110	--	700	208	195	149	260	11	225	114	269	7
72	--	700	182	213	183	237	11	202	233	215	10
650	--	700	146	160	152	234	12	162	193	242	10
-110	10	700	284	87	48	294	6	--	68	--	--
72	10	700	255	259	172	264	5	268	136	276	6
650	10	700	218	175	166	251	9	230	175	262	9
-110	--	750	219	190	59	264	10	225	86	269	14
72	--	750	187	238	172	237	11	204	182	252	10
650	--	750	152	180	159	235	11	164	--	236	6

(a) Processed from 10-in.-square ingot to 3/4-in.-thick plate then rolled to 0.100-in.-thick sheet. The notched and smooth specimens were ground to 0.025 and 0.090 in. thickness, respectively. All specimens represented the longitudinal direction and were austenitized at 1900 F for 1/2 hr, oil quenched, refrigerated at -100 F for 1/2 hr or cold rolled 10 percent, and then tempered at the indicated temperature for 2+2 hr.

TABLE 61. TENSILE PROPERTIES OF AFC-77 SHEET TEMPERED AT 500 F[(a)]

Heat Treatment	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, % in 2 in.
2000 F ½ hr, oil quenched, 500 F 2+2 hr	131	211	14
2000 F ½ hr, oil quenched, 500 F 4 hr	128	214	15
1900 F ½ hr, oil quenched, 500 F 2+2 hr	140	217	14
1900 F ½ hr, oil quenched, 500 F 4 hr	141	218	15
1800 F ½ hr, oil quenched, 500 F 2+2 hr	171	217	11
1800 F ½ hr, oil quenched, 500 F 4 hr	168	215	11

(a) Processed from 10-in.-square ingot to 3/4-in.- thick plate; then rolled to 0.100-in.-thick sheet. All specimens longitudinal direction.

TABLE 62. RESULTS OF FRACTURE TOUGHNESS TESTS MADE ON AFC-77 SHEET[(a,b)]

Tempering Temperature, F	Cold Reduction, percent	Tensile Strength, ksi	Net Fracture Stress, ksi
600	--	258	193
700	--	245	194
800	--	259	181,193
800	5	281	224,217
800	10	297	179,204
800	15	308	81,85
900	--	277	73,70
1000	--	285	60,65
1100	--	290	46,44

(a) Heat treatment: austenitized at 2000 F, oil quenched, refrigerated at -100 F for 1/2 hr or cold rolled, and then tempered at the indicated temperature for 2+2 hr.
(b) Two-in.-wide center-notch fatigue-cracked specimens.

TABLE 63. CREEP-RUPTURE TESTS ON AFC-77 AUSTENITIZED AT 2000 F[(a)]

Heat Treatment: Austenitizing Temperature, F	Heat Treatment: Tempering Temperature, F	Test Conditions: Temperature, F	Test Conditions: Stress, ksi	Rupture: Life, hr	Rupture: Elongation, percent	Rupture: Reduction of Area, percent	Minimum Creep Rate, %/hr x 10^{-2}	Melting Process	Form
2000	900	900	200	113	11	41	--	Air	Bar
			190	354	3	2	--	Air	Bar
			180	>2643	--	--	--	Air	Bar
			170	>1082	--	--	--	Air	Bar
2000	1100	1000	175	30	8	13	--	Air	Bar
			160	135	7	17	4.2	Air	Sheet
			160	188	12	35	1.3	Vac	Bar
			150	331	7	18	0.75	Air	Bar
			150	259	15	35	1.3	Vac	Bar
			140	370	9	21	1.0	Air	Bar
			140	491	6	8	0.57	Air	Sheet
			140	477	13	37	0.98	Vac	Bar
			125	1065	12	28	--	Air	Bar
			120	1750	--	--	--	Air	Bar
2000	1100	1100	100	39	13	33	--	Air	Bar
			100	47	13	46	9.6	Vac	Bar
			90	108	12	18	3.9	Air	Bar
			90	92	15	47	--	Vac	Bar
			90	102	9	35	3.6	Air	Sheet
			90	194	13	15	2.7	Air	Bar
			75	285	19	26	1.7	Air	Bar
			75	249	10	21	1.2	Air	Sheet
			75	271	12	21	1.36	Vac	Bar
			75	366	8	14	1.1	Air	Bar
			60	485	11	21	--	Air	Bar
			55	538	11	19	--	Air	Bar
2000	1100	1200	40	67	12	18	7.5	Vac	Bar
			35	68	13	23	--	Vac	Bar
			35	73	24	24	7.5	Air	Bar
			35	114	24	26	3.4	Air	Sheet
			35	103	18	17	--	Air	Bar
			30	148	16	26	4.1	Air	Bar
			30	153	21	30	3.1	Vac	Bar

(a) Heat treatment: austenitized 2000 F 1 hr (bar) or 1/2 hr (sheet), oil quench, -100 F 1/2 hr, temper at the indicated temperature 2+2 hr.

TABLE 64. CREEP-RUPTURE TESTS ON AFC-77 AUSTENITIZED AT 1900 F[(a)]

Heat Treatment: Austenitizing Temperature, F	Heat Treatment: Tempering Temperature, F	Test Conditions: Temperature, F	Test Conditions: Stress, ksi	Rupture: Life, hr	Rupture: Elongation, percent	Rupture: Reduction of Area, percent	Minimum Creep Rate, %/hr x 10^{-2}	Melting Process	Form
1900	900	900	180	>1000	--	--	--	Air	Bar
1900	1000	900	180	>1000	--	--	--	Air	Bar
1900	1100	900	180	557	18	39	--	Air	Bar
1900	1100	1100	90	63	28	64	--	Air	Bar
			90	137	21	47	3.5	Air	Bar
			75	170	17	37	--	Air	Bar
			75	221	13	31	2.0	Air	Bar

(a) Heat treatment: austenitized 1900 F 1 hr, oil quench, -100 F 1/2 hr, temper at the indicated temperature 2+2 hr.

TABLE 65. EFFECT OF AUSTENITIZING TEMPERATURE ON CREEP-RUPTURE PROPERTIES OF AFC-77 AT 1000 F[a]

Austenitizing Temperature, F	Tempering Treatment	Stress, ksi	Rupture Life, hr		Elongation, percent	Reduction of Area, percent
			Smooth	Notched[b]		
2000	1400 F - 2+2 hr	90	586	86.8	19	43
1950	1400 F - 2+2+2 hr	90	273	556	16	48
1900	1400 F - 2+2+2 hr	90	361	799	19	48
1900	1400 F - 2+2+2 hr	90	320	847	19	52
1850	1400 F - 2+2+2 hr	90	353	312	20	52

(a) Held at the austenitizing temperature indicated for 1 hr, oil quenched, refrigerated at -100 F for 1/2 hr, and then tempered as indicated.
(b) K_t = 3.9.

TABLE 66. CREEP-RUPTURE TESTS ON AFC-77 TEMPERED AT 1400 F[a]

Test Temperature, F	Stress, ksi	Rupture Life, hr		Elongation, percent	Reduction of Area, percent	Minimum Creep Rate, 10^{-4} in./in./hr
		Smooth	Notched[b]			
1000	100	119	329	20	53	1.8
1000	90	361	799	19	48	--
1000	85	696	1164	19	50	0.81
1000	75	1371	669	24	46	0.68
1050	90	29.5	78.9	30	60	13.1
1050	75	116	145	31	57	5.9
1050	55	1073	1254	14	32	0.37

(a) Heat treatment: austenitized at 1900 F for 1 hr and oil quenched; refrigerated at -100 F for 1/2 hr; tempered at 1400 F for 2+2+2 hr.
(b) K_t = 3.9.

TABLE 67. TENSILE PROPERTIES OF AFC-77 TEMPERED AT 1400 F[a]

Test Temperature, F	0.2% Yield Strength, ksi	Tensile Strength, ksi	Elongation in 1.4 In., percent	Reduction of Area, percent
70	135	177	15	46
70	130	175	14	44
1000	121	152	19	51
1000	122	151	19	51
1050	112	135	20	58
1050	113	135	21	60

(a) Heat treatment: austenitized at 1900 F for 1 hr, oil quenched; refrigerated at -100 F for 1/2 hr; tempered at 1400 F for 2+2+2 hr.

The results of Charpy V-notch impact tests on specimens from 1/2-in.-diam AFC-77 bar are shown in Table 68. Minimum room-temperature impact values are obtained on tempering in the 900 to 1100 F range. As would be expected, the impact strength of AFC-77 is somewhat higher at 500 F than at 75 F.

Physical Properties

The mean coefficients of linear thermal expansion listed in Table 69 were calculated from dilatometer measurements on AFC-77 bar stock in the 1100 F temper.

Fabrication and Cleaning

AFC-77 steel-bar stock can be fabricated into machined parts after the -100 F refrigeration step in the heat treatment. The hardness of the alloy in this condition is approximately R_c 46. High-speed steel is a satisfactory tool material. Surface finishes are comparable to those obtained on heat-treated low-alloy steels. All parts should be degreased and water rinsed before double tempering at 900 or 1100 F. The heat tint from tempering may be removed by standard stainless-steel pickling procedures.

TABLE 68. RESULTS OF CHARPY V-NOTCH IMPACT TESTS ON AFC-77

Tempering Temperature,(a) F	Hardness, R_c	Charpy V-Notch Impact Value, ft-lb Tests at 75 F	Tests at 300 F	Tests at 400 F	Tests at 500 F
700	49	13	--	--	31
800	51	5	--	--	30
900	52	3	--	8	--
1000	53	3	--	--	12
1100	52	4	7	--	--
1200	47	6	--	--	17
1300	41	8	--	--	20
1350	39	12	--	--	29
1400	40	13	--	--	29
1450	40	11	--	--	22
1100+1400	40	13	--	--	29
1100+1350	40	11	--	--	27
1400+1100	41	4	--	--	24
1400+1200	39	6	--	--	26

(a) Heat treatment: austenitized at 1900 F for 1 hr, oil quenched, refrigerated at -100 F for 1/2 hr, and tempered at the indicated temperature for 2+2 hr.

AFC-77 steel sheet is austenitized, quenched, tempered at 500 F, pickled, and stretcher leveled at the mill. The material in this condition has mechanical properties shown in Table 61 and can be bent 180 degrees around a radius two times the thickness. AFC-77 can be formed by most conventional methods used for austenitic stainless steels, although equipment power requirements may be greater due to higher yield strength. Temper tooling (jigging and fixturing) is required in final heat treatment to control warpage and insure proper part dimensions. The temper oxide may be removed by short-time immersion in 10%HNO_3-2%HF pickling solution. All parts should be passivated in 40 to 60 percent HNO_3 as the final processing step.

Welding

AFC-77 can be welded by the tungsten inert-gas process. Filler metal, if added, should be of the same composition. The tensile properties for welded specimens, listed in Table 70, show good weld-joint efficiencies after tempering at 1100 F.

Corrosion

AFC-77 steel in accelerated corrosion tests has corrosion resistance comparable to that of several high-strength semiaustenitic stainless steels. Exposure of AFC-77 to water vapor in alternate 8-hr wet and 4-hr dry cycles for 3 days caused only light stain on the specimen surface. Spraying for 16 hr at 120 F with an aqueous solution of NaCl and $CuCl_2$ acidified with acetic acid to a pH of 3.2 caused some pitting in AFC-77 specimens. Similar results were found on PH15-7Mo and AM-350 stainless steels tested under the same conditions. Oxidation tests in still air at the maximum expected service temperature, 1200 F, for 500 hr resulted in a weight gain of only 0.5 mg/cm^2 for AFC-77 specimens.

TABLE 69. COEFFICIENT OF THERMAL EXPANSION OF AFC-77(a)

Temperature Range, F	Mean Coefficient of Linear Thermal Expansion, in./in./F
77-200	5.3×10^{-6}
77-300	5.60
77-400	5.63
77-500	5.77
77-600	5.87
77-700	5.97
77-800	6.09
77-900	6.22
77-1000	6.37
77-1100	6.41
77-1200	6.41

(a) Heat treatment: austenitized 2000 F 1 hr, oil quenched, -100 F 1/2 hr, tempered 2+2 hr 1100 F.

TABLE 70. TENSILE PROPERTIES OF WELDED AND UNWELDED SHEET SAMPLES OF MILL-PROCESSED AFC-77

Welding and Heat-Treatment Sequence(a)	Sheet Thickness, in.	0.2% Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 In., percent	Location of Fracture
		Welded Specimens			
R,A,W,TL	1/16	216	285	3.5	Heat-affected zone
R,A,W,TL	1/16	226	285	3.5	Ditto
R,W,TL	1/16	209	276	4	"
R,W,TL	1/16	207	274	5	"
R,A,W,TL	1/8	219	283	2	Weld metal
R,A,W,TL	1/8	217	287	3.5	Heat-affected zone
R,A,W,TN	1/8	221	282	5	Ditto
R,A,W,TN	1/8	219	283	5	"
R,W,TL	1/8	206	271	6.5	"
R,W,TL	1/8	205	270	6	Base metal
R,A,W,TM	1/8	222	286	3.5	Heat-affected zone
R,A,W,TM	1/8	220	286	3.5	Ditto
		Unwelded Specimens			
R,A,TL	1/8	219	291	8	--
R,A,TL	1/8	219	289	7	--
R,TL	1/8	217	290	7	--
R,TL	1/8	225	297	7.5	--
R,A,TM	1/8	224	294	7	--
R,A,TM	1/8	224	296	7.5	--

(a) R: hot rolled; A: austenitized, 2000 F, 15 min, air cooled; W: TIG welded, no added filler metal; TL: -100 F 1/2 hr, 1100 F 2+2 hr; TM: -100 F 1/2 hr, 1100 F 2 hr, -100 F 1/2 hr, 1100 F 2 hr; TN: 1100 F, 1+1+2 hr.

Several series of stress-corrosion tests have been conducted on AFC-77 steel sheet for various heat-treat and exposure conditions. The data listed in Tables 71, 72, and 73 show erratic results. The general trend of the data indicates that some improvement in stress-corrosion resistance might be expected from AFC-77 austenitized at 1800 or 1900 F and tempered at 800 F or lower.

Availability and Usage

AFC-77 is being developed as bar, billet, and sheet product. It is intended primarily for structural applications at elevated temperatures in the range from 700 to 1200 F. The alloy also has been used as die and tool material.

TABLE 71. STRESS-CORROSION TESTS OF AFC-77[a]

Tempering Temperature,[b] F	Melting Method	Hardness, R_c	Time to Failure, days[c]: Exposure to Pittsburgh Industrial Atmosphere	Atmospheric Exposure Plus Swabbed Daily With 5% NaCl	Indoor Exposure Plus Sprayed Daily With 5% NaCl
800	Air	53	357 NF	22	3
			357 NF	5	96
			357 NF	1	--
900	Air	53	7	1	--
			7	1	--
			6	1	--
1100	Air	54	357 NF	5	7
			357 NF	2	5
			357 NF	1	--
800	Vac	52	24 NF	--	331 NF
					331 NF
1100	Vac	54	24 NF	--	5
					4

(a) Two point-loaded bent-beam 0.060-in.-thick specimens stressed to 150,000 psi.
(b) Heat treatment: austenitized 2000 F 15 min, oil quenched, -100 F 1/2 hr, tempered at temperature indicated 2+2 hr.
(c) NF: no failure.

TABLE 72. EFFECTS OF AUSTENITIZING AND TEMPERING TEMPERATURE ON THE STRESS-CORROSION RESISTANCE OF AFC-77[a,b]

Tempering Temperature, F	1800: Hardness, R_c	1800: Time to Failure,[c] days	1900: Hardness, R_c	1900: Time to Failure,[c] days	2000: Hardness, R_c	2000: Time to Failure,[c] days	2100: Hardness, R_c	2100: Time to Failure, days	2150: Hardness, R_c	2150: Time to Failure, days
800	50	6	53	2	53	287 NF	53	1	53	1
		3		2		13		1		1
900	51	5	53	1	53	1	53	1	53	1
		2		2		1		1		1
1000	51	33	53	27	54	21	53	22	54	10
		29		15		23		15		13
1100	--	287 NF	--	287 NF	53	13	54	5	54	6
		287 NF		287 NF		20		6		5

Austenitizing Temperature, F (column groups 1800, 1900, 2000, 2100, 2150)

(a) 0.060-in.-thick specimens loaded as bent beams, stressed to 125,000 psi, and exposed to the atmosphere, plus sprayed daily with salt solution (5% NaCl + 1% zephiran chloride in aqueous solution).
(b) Heat treatment: austenitized at indicated temperature for 15 min, oil quenched; refrigerated at -100 F for 1/2 hr, and tempered at the indicated temperature for 2+2 hr.
(c) NF: no failure.

TABLE 73. EFFECTS OF AUSTENITIZING TEMPERATURE, TEMPERING TEMPERATURE, AND COLD ROLLING ON THE RESISTANCE OF AFC-77 TO STRESS CORROSION[a,b]

	Austenitized at 2000 F + Refrigeration		Austenitized at 1900 F + Refrigeration		Austenitized at 1900 F + Cold Reduction		Austenitized at 1800 F + Refrigeration		Austenitized at 1800 F + Cold Reduction	
Tempering Temperature, F	Hard ness, R_c	Time to Failure,[c] days	Hard-ness, R_c	Time to Failure,[c] days	Hard-ness, R_c	Time to Failure,[c] days	Hard-ness, R_c	Time to Failure,[c] days	Hard-ness, R_c	Time to Failure,[c] days
700	--	--	49	153 NF	54	15	48	153 NF	52	153 NF
		--		153 NF		153 NF		153 NF		153 NF
750	--	--	50	153 NF	55	9	49	153 NF	53	153 NF
		--		153 NF		138		153 NF		153 NF
800	--	--	51	153 NF	55	5	50	153 NF	54	153 NF
				153 NF		138		153 NF		153 NF
900	53	47	51	4	--	--	--	--	--	--
		4		5		--		--		--
1000	--	--	52	50	--	--	--	--	--	--
		--		84		--		--		--
1100	55	15	52	15	--	--	--	--	--	--
		14		153 NF		--		--		--

(a) 0.050-in.-thick specimens loaded as bent beams, stressed to 125,000 psi, and exposed to the atmosphere plus daily spraying with salt solution (5% NaCl + 1% zephiran chloride in aqueous solution).
(b) Heat treatment: austenitized at indicated temperature for 1/2 hr, oil quenched, refrigerated at -100 F for 1/2 hr or cold rolled 10%, and tempered at the indicated temperature for 2+2 hr.
(c) NF: no failure.

REFERENCES

(1) "Armco PH14-8Mo Precipitation-Hardening Stainless-Steel Sheets and Strip", Product Data Bulletin S-24, Armco Steel Corporation, Middletown, Ohio, not dated.

(2) Perry, D. C., Tanczyn, H., and Clarke, W. C., Jr., "New PH Steel Matches Strength and Toughness", Metal Progress, 83, p. 101 (June, 1963).

(3) "Data Sheet--PH13-8Mo Stainless Steel--Bar, Wire, Plate & Forging Billet", Armco Steel Corporation, Research and Technology, Middletown, Ohio, not dated.

(4) Clarke, W. C., Jr., and Garvin, H. W., "Effect of Composition and Section Size on Mechanical Properties of Some Precipitation-Hardening Stainless Steels", taken from ASTM Special Technical Publication No. 369, entitled Advances in the Technology of Stainless Steels and Related Alloys, published by the ASTM, Philadelphia, Pennsylvania (1965).

(5) "Armco 15-5PH Precipitation-Hardening Stainless Steel Bar and Wire", Product Data Bulletin S-21, Armco Steel Corporation, Middletown, Ohio, not dated.

(6) "Armco 17-4PH Sheets and Strip", Product Data Bulletin S-9, Armco Steel Corporation, Middletown, Ohio, not dated.

(7) "Preliminary Technical Data Sheet on Carpenter Custom 455", Carpenter Steel Company, Reading, Pennsylvania, not dated.

(8) Aggen, G. N., Hammond, C. M., and Lula, R. A., "New Martensitic Age Hardening Stainless Steels", taken from ASTM Special Technical Publication No. 369, entitled Advances in the Technology of Stainless Steels and Related Alloys, published by the ASTM, Philadelphia, Pennsylvania (1965).

(9) Kasak, A., Chandhok, V. K., and Dulis, E. J., "Development of New and Useful Elevated-Temperature Steels for Aircraft Applications", Report No. ASD-TR-61-386, Crucible Steel Company of America, Pittsburgh, Pennsylvania, under Air Force Contract AF 33(616)-7376 (June, 1962).

(10) Kasak, A., Chandhok, V. K., Moll, J. H., and Dulis, E. J., "Development of High-Strength Elevated-Temperature, Corrosion-Resistant Steel", Report No. ASD-TDR-63-766, Crucible Steel Company of America, Pittsburgh, Pennsylvania, under Air Force Contract AF 33(657)-8458 (September, 1963).

LIST OF DMIC TECHNICAL REPORTS ISSUED

DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
Columbus, Ohio 43201

Copies of the technical reports listed below may be obtained, while the supply lasts, from DMIC at no cost by Government agencies, and by Government contractors, subcontractors, and their suppliers. Qualified requestors may also order copies of these reports from the Defense Documentation Center (DDC), Cameron Station, Building 5, 5010 Duke Street, Alexandria, Virginia 22314. A complete listing of previously issued DMIC reports may be obtained by writing DMIC.

DMIC Number	Title
215	Thin-Sheet Rolling, Report of an Informal Symposium of the Metalworking Processes and Equipment Program (MPEP), May 17, 1965 (AD 465246)
216	Corrosion of Materials by Ethylene Glycol-Water, May 10, 1965 (AD 466284)
217	Physical Metallurgy of Alloy 718, June 1, 1965 (AD 466476)
218	Third Status Report of the U. S. Government Metalworking Processes and Equipment Program, June 16, 1965 (AD 468246)
219	Hydrogen Movement in Steel - Entry, Diffusion, and Elimination, June 30, 1965 (AD 474578)
220	Comparison of Chemical Analyses of Refractory Alloys - A Survey Conducted by the Materials Advisory Board as Part of the Refractory Metals Sheet Rolling Program (RMSRP), September 10, 1965 (AD 473980)
221	Fourth Status Report of the U. S. Government Metalworking Processes and Equipment Program, December 7, 1965
222	High-Purity Metals, January 3, 1966

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Defense Metals Information Center Battelle Memorial Institute 505 King Avenue, Columbus, Ohio 43201	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

New Developments in High-Strength Stainless Steels

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

DMIC Report

5. AUTHOR(S) *(Last name, first name, initial)*

Hoenie, A. F., and Roach, D. B.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 3, 1966	40	10

8a. CONTRACT OR GRANT NO. AF 33(615)-3408	9a. ORIGINATOR'S REPORT NUMBER(S) DMIC Report 223
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. AVAILABILITY/LIMITATION NOTICES Copies of this report may be obtained, while the supply lasts, from DMIC at no cost by Government agencies, contractors, subcontractors, and their suppliers. Qualified requestors may also obtain copies of this report from the Defense Documentation Center (DDC), Alexandria, Virginia 22314.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Air Force Materials Laboratory Research and Technology Division Wright-Patterson Air Force Base, Ohio

13. ABSTRACT This report presents information on the physical metallurgy, chemical composition, mechanical and physical properties, corrosion resistance, fabrication, and cleaning of several of the newer high-strength stainless steels. The alloys covered in this report include one semiaustenitic precipitation-hardenable stainless steel, PH14-8Mo, and the following martensitic precipitation-hardenable stainless steels: PH13-8Mo, 15-5PH, Custom 455, AM-363, AM-362, and AFC-77. Also included is 17-4PH as a sheet and strip product.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Physical metallurgy	8	3				
Chemical composition	8	3				
Mechanical properties	8	3				
Physical properties	8	3				
Corrosion resistance	8	3				
Fabrication	8	3				
Cleaning	8	3				
Stainless steel	8,9	3				
High strength	0	3				
Semiaustenitic precipitation hardenable	0	3				
Martensitic precipitation hardenable	0	3				
PH14-8Mo	8,9	3				
PH13-8Mo	8,9	3				
15-5PH	8,9	3				
Custom 455	8,9	3				
AM-363	8,9	3				
AM-362	8,9	3				
AFC-77	8,9	3				
17-4PH	8,9	3				